PREDICTION OF COW FERTILITY BASED ON PRODUCTIVITY TRAITS IN DAIRY CATTLE UNDER DIFFERENT PRODUCTION SYSTEMS

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DEDICATION

To my dear mama

DECLARATION

I declare that I composed the present thesis. This is my own work and any assistance has been duly acknowledged. The work described has not been submitted for any other degree or professional qualification.

Signature: ..…………………………….

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Date: ……………………………..

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ACRONYMNS

Acronyms used in this thesis are listed below. A few other acronyms are described within chapters of this thesis.

ADD	Agricultural Development Division
AEDO	Agricultural Extension Development Officer
AHEE	Acid Hydrolysis Ether Extract
AI	Artificial Insemination
AIT	Artificial Insemination Technician
AVO	Agricultural Veterinary Officer
AUC	Area Under the Curve
BCS	Body Condition Score
BEC	Body Energy Content
BPC	By-product Control
BPS	By-product Select
CLA	Commencement of Luteal Activity
CP	Crude Protein
DAHLD	Department of Animal Health and Livestock Development
DFHLA	Days to First High Luteal Activity
DFOH	Days to First Observed Heat
DFS	Days to First Service
DM	Dry Matter

DMI	Dry Matter Intake
DSS	Days to Successful Service
ECF	East Coast Fever
EFSA	European Food Safety Authority
EPA	Extension Planning Area
FAO	Food and Agriculture Organization
FICA	Flanders International Cooperation Agency
FMD	Foot and Mouth Disease
HFC	High Forage Control
HFS	High Forage Select
HGC	Home-grown Control
HGS	Home-grown Select
IBSNAT	International Benchmark Sites Network for Agrotechnology Transfer
ICAR	International Committee for Animal Recording
ICC	Intraclass Correlation Coefficient
IFCN	International Farm Comparison Network
IGF	Insulin-like Growth Factor
LADD	Lilongwe Agricultural Development Division
LFC	Low Forage Control
LFS	Low Forage Select
LPS	Large-scale Production Systems

LUANAR	Lilongwe University of Agriculture and Natural Resources
MAFF	Ministry of Agriculture Fisheries and Food
MBG	Milk Bulking Group
ME	Metabolisable energy
MYA	Milk Yield Acceleration
MYP	Malawi Young Pioneers
NASS	National Agricultural Statistics Service
NCGD	Neutral Cellulose Gaminase Digestibility
NEB	Negative Energy Balance
NEFA	Non-Esterified Fatty Acids
NGO	Non-Governmental Organization
NIRS	Near Infrared Reflectance Spectroscopy
NRC	National Research Council
NSO	National Statistics Office
PDR	Pregnancy Diagnosis Results
PTA	Predicted Transmission Ability
ROC	Receiver Operating Characteristic
SAS	Statistical Analysis System
SD	Standard Deviation
SEM	Standard Error of the Mean
SPS	Smallholder Production Systems
SRUC	Scotland's Rural College

TMR	Total Mixed Ration
UK	United Kingdom
USA	United States of America
VIF	Variance Inflation Factor
VWP	Voluntary Waiting Period

ABSTRACT

A study to examine factors that influence dairy cattle fertility was conducted in the United Kingdom (UK) and Malawi. Productivity data from the UK comprising 56,014 records from 574 Holstein cows were retrieved from a database at Scotland's Rural College Dairy Research Centre in Dumfries. The cows were of either high (select) or average (control) genetic merit and fed total mixed rations with high or low forage. These formed four production systems - high forage select (HFS), low forage select (LFS), high forage control (HFC) and low forage control (LFC). Data from Malawi were obtained through a baseline survey in 67 smallholder farms and monitoring of 28 and 62 dairy cows from smallholder farms and a commercial farm, respectively. The breeds were Holstein-Friesians and Holstein-Friesian x Malawi Zebu crosses predominantly fed forages supplemented with concentrates. Some cows were fitted with accelerometers to enable monitoring of cow activity which was then related to cow fertility and energy balance. The data were analysed using descriptive statistics, mixed models and logistic regression models using SAS 9.3.

The UK data showed that production system significantly ($p<0.05$) influenced milk yield, body energy content (BEC) and fertility. BEC is a trait that indicates absolute level of energy in the body per day regardless of energy use and intake the previous day. Daily milk yield of LFS cows was 35±0.1 (mean±SEM) litres which was significantly ($p<0.05$) higher than that of LFC (30.4±0.1 litres), HFS (27.5±0.1 litres) and HFC (24.3±0.1 litres) cows. LFS cows also had the highest milk yield acceleration to peak milk yield (0.51 litres/day/day) than (LFC 0.47±0.02 litres/day/day), HFC (0.47±0.03 litres/day/day) and HFS (0.46±0.03 litres/day/day) cows. The interval from calving to nadir BEC was 68±5, 83±6, 88±5 and 106±6 days for LFC, LFS, HFC and HFS cows, respectively. Days to first high luteal activity (DFHLA)

and days to successful service (DSS) were significantly different with production system and genetic merit, respectively. LFC cows had DFHLA of 27±2 days (mean±SEM) which were significantly lower ($p<0.05$) than those of HFC (30±3 days), HFS (30±2 days) and LFS (35±3 days) cows. Average genetic merit cows had significantly lower ($p<0.05$) DSS (119±5 days, mean±SEM) than high genetic merit cows (132±5 days). Results from data collected in Malawi showed variations that reflected differences in management and other environmental factors. Average daily milk yield per lactation in Malawi was 13.3±4.9 (mean±SD) litres. Fertility traits in the UK herd were better than those in Malawi herds. The average DFHLA in Malawi was 79±29 days while in the UK it was 31±18 days. Cow activity in both the UK and Malawi farms varied with the feeding system, genetic merit and BEC. Select cows on home grown feeding system were more active (motion index =6250±40), stood longer (13.4±0.04 hours/day) and spent more time eating (5.6±0.32 hours/day, mean±SEM) than select cows on by products feeding system that had motion index, standing and eating time of 5166±37, 11.9±0.04 hours/day and 4.6±0.16 hours/day, respectively.

Genetic merit, lactation number, days to first observed oestrus, calving BEC, service BEC and service milk yield were significant predictors of pregnancy to first insemination ($p<0.05$) while genetic merit, milk yield, percentage BEC between calving and service, service milk yield and service BEC were significant predictors ($p<0.05$) of pregnancy to the first three inseminations. Validation of models derived showed C-statistics of the receiver operating characteristic (ROC) curve of 0.66 (95% confidence interval (CI): 0.57 to 0.75) and 0.65 (CI: 0.55-0.75), respectively. It is concluded that genetic merit, feeding system, parity, energy status and stage of lactation are the major factors that determine the likelihood of achieving pregnancy following insemination. Models developed have a potential to predict the probability of pregnancy to an insemination at an acceptable level of accuracy.

PUBLICATIONS

Research Article (peer reviewed)

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CHAPTER 1: GENERAL INTRODUCTION

Milk production from the modern high producing dairy cow has been challenged by declining fertility over the past 30 years (Lucy, 2003; Leroy et al., 2008; Lovendahl et al., 2009; Roche et al., 2009; Bello et al., 2012) and this has been attributed to the antagonistic genetic relationship between fertility and milk yield (Pryce et al., 2004; Lovendahl et al., 2009) as well as management differences between production systems and regions (McDougall, 2006, Mee, 2012). A recent review by Bello et al. (2012) not only asserts to the negative relationship between milk yield and fertility but also highlights the existence of other confounding factors such as metabolite production, age and the health status of the cow.

The challenge of low fertility occurs not only in high yielding herds in developed countries, but also in developing countries such as Malawi, Kenya, Tanzania, Ethiopia and Zimbabwe (Msanga et al., 2000; Bebe et al., 2003a; Masama et al., 2003; Banda et al., 2011). Low fertility is associated with many health, physiological and management factors (Lucy, 2003). In many developing countries, the problem of low fertility under smallholder farming systems is closely associated with management as evidenced by inadequate management skills and limited access to appropriate resources and services such as extension, health and finance (Bebe et al., 2003b; Chindime, 2008). In developed countries where management skills and access to resources are less constrained, low fertility is more associated with production systems, energy balance, genotype and other physiological factors (Pryce et al., 2004; Pollot & Coffey, 2008; Mee, 2012).

1.1 Fertility and dairy production systems

Although addressing the problem of low fertility in different production systems may require different approaches, similar basic principles could be applied. This is because the biology underlying dairy cattle productivity is the same between breeds and regions. Dairy husbandry practices are developed based on the understanding of this biology. For instance the practice to decide on insemination time depending on when oestrus is first observed is based on the understanding of when ovulation occurs from the time oestrous behaviours are first observed. Hence the husbandry practices in dairy production are similar across regions with some variations due to differences in climate, access to resources, available skills and scale of production. These variations create the different production systems that exist. The two major dairy production systems are smallholder and large scale production. Smallholder production systems are generally low input-output systems with relatively small herd sizes. Large-scale production systems are characterised by relatively large herd sizes, high inputs and productivity. The smallholder production systems are more prevalent among resource constrained households in developing countries while large scale production systems are more common and well established in developed countries. Both production systems face the challenge of declining cow fertility and various efforts have been put in place to address the problem. Despite these efforts, the challenge still persists (Bello et al., 2012). This thesis describes a novel approach, using existing understanding of the association of cow fertility with other cow productivity traits, to characterise and address dairy cow infertility in different production systems.

1.2 Fertility and other production factors

Cow fertility is associated with production factors such parity, body energy reserves, health status, milk yield and composition (Chagas et al., 2007; Friggens et al., 2007; Roche et al., 2009) which are influenced by nutrition among other factors. Robinson et al. (2006) reported that nutrition influences fertility through supply of nutrients required for various reproductive processes. Hence dairy cattle feeding ought to meet the nutritional requirements of an animal at any particular stage of production for optimum lifetime productivity to be achieved. Optimum lifetime productivity in this case would include timely resumption of oestrus after calving and minimising the impact of factors which increase the risk of culling. Whether nutritional requirements are being met or not is often depicted by the body condition score (BCS) and the milk yield which in turn reflect on fertility (Roche et al., 2009). The higher the BCS, the better the nutritional status until a certain level where over nutrition may result.

However, provision of appropriate feeds to meet the nutritional requirements of the dairy cows is often a challenge in many dairy production systems. In well managed dairy systems, the main challenges are feed quality and balancing nutrients in relation to cost effectiveness and environmental impact. Smallholder farming systems such as those prevalent in Malawi, Kenya and other developing countries have provision of adequate good quality feed as an additional challenge (Lanyasunya et al., 2005; Gibbons et al., 2010). Therefore the aim of this research was to determine how monitoring of dairy cow productivity in relation to feeding systems could be used to improve fertility in different production systems. The approach used is similar to that used in human medicine where epidemiological data are used to predict disease treatment outcomes based on associations between patients and other known parameters (Siontis et al., 2012). In the current study, associations between dairy production systems, body condition scores, body weights, milk yield and fertility were explored and used to determine whether routinely collected cow productivity data could be used to develop a model to predict the outcome of inseminations. It was envisaged that such a model could become a management tool to facilitate insemination decisions given options to use high value semen such as sexed semen, ordinary semen, natural mating or not inseminating at all. A decision on such scenarios would be based on the likelihood for pregnancy derived from the model.

1.3 Research approach

The research was conducted with an understanding of challenges associated with data acquisition in developing countries. The research approach was similar to that described by Uehara & Tsuji (1998), which used systems analysis and simulation to complement experimentation in developing countries. The approach described by Uehara & Tsuji (1998) was under a project called International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) and used the understanding of links between production systems that enabled testing of models and comparisons of observed and predicted crop yields and number of days to maturity. It demonstrated that models could operate both locally and globally through using data and that despite some shortfalls, probabilities on likely outcomes could be generated to enable the visualisation of associated risks and opportunities.

The current study also aimed to develop a generic model from more reliable data available from a United Kingdom (UK) herd and test it on data from a specific production system in Malawi. The study dealt with production of the same breed (Holsteins) of cattle in a developing country (Malawi) and a developed country (UK). Notwithstanding the climatic differences, dairy production in Malawi is faced with challenges related to management and access to resources which result in relatively poor productivity when compared with the same breeds in the UK where management levels are much higher and recording is routine and more accurate. The study approach was to build on the fact that high productivity in the UK is also largely due to appropriate management linked to resource availability and expertise. Hence it was hypothesised that data from UK production systems would provide insight into interventions that can be made to improve dairy productivity in Malawi with emphasis on the interaction between fertility and the production systems.

1.4 Objectives

1.4.1 General Objective

- To examine factors that influence fertility and use these factors to develop and test a pregnancy predictive model for dairy cattle.

1.4.2 Specific Objectives

These were to:

- Identify factors that are associated with successful pregnancy in dairy cows under high and low forage feeding systems from the Langhill herd at SRUC Dairy Research Centre;
- Monitor the factors associated with successful pregnancy in the Langhill herd, in smallholder and commercial production systems in Malawi;
- Determine the effect of production systems on cow activity and fertility;
- Develop a model that could predict the likelihood of pregnancy in dairy cows under different feeding systems; and
- Validate the pregnancy prediction model using data from Malawi and a different herd in the UK

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Dairy production in both developing and developed countries is an important source of food and income. Gerosa & Skoet (2012) reported a substantial increase in the production and consumption of milk and milk products due to increased income levels and economic growth over the past two decades. The increased milk production is reflected in world milk production trends over the years with both developed and developing countries contributing different proportions. FAO (2013) data showed that the top ten cow milk producing countries in 2011 were dominated by developed countries. Despite the country rankings in milk production, Gerosa & Skoet (2012) reported that the increase in milk production in some developing countries was significantly higher than that of developed countries. Such a scenario was attributed to both demand and technological advances that led to emergence of large-scale dairy production. Smallholder farmers remained an important contributor to increased dairy production in developing countries.

The level of productivity in dairy farms is largely determined by the type of production system used. Livestock production systems are described either as part of mixed farming systems or as entire farming systems depending on whether livestock production is mixed with other enterprises or the sole activity of the farm. A farming system is defined as a population of farms with a similar structure and function such that they are likely to have similar production functions (Ruthernberg, 1980). Farms within the same farming system have broadly similar resource bases, enterprise patterns, household livelihoods, constraints, development strategies and interventions. Several livestock production systems have been described with varying names and classification criteria. Criteria for classifications include intensity of production, level of integration with other farm enterprises, animal-land relationship and agro-ecological zones (Sere & Steinfield, 1996; De Leeuw et al., 1999; Kruska et al., 2003; Damron, 2009; McDermont et al., 2010).

This review will concentrate on dairy production systems that are described based on level of intensification and will consider smallholder and large-scale dairy production systems. The differences between the two systems are in terms of their operation sizes, management level and input use (Muriuki, 2011) which are in turn reflected in their productivity. Smallholder production systems (SPS) are generally low input-output systems and are associated with relatively small herd sizes. Large-scale production systems (LPS) are relatively large herds with high inputs and productivity. The actual herd sizes and inputs in both systems are quite variable across regions and livestock systems (Table 2.1). There seems to be no clear demarcation based on numbers between SPS and LPS although Aleri et al., (2012) defined smallholder farms as those farms with a maximum of 16 adult dairy cows. Coetzee (2012) included use of family labour as another distinguishing characteristic of smallholder farms while Muriuki (2011) alluded to their feeding systems mainly relying on forage and small quantities of concentrate. However, use of family labour and high reliance on forage is also associated with LPS (Hemme & Otte, 2010).

Studies in Sub-Saharan Africa show that SPS have average herd sizes ranging from 2 to 24 (Gitau et al., 1994; Bebe et al., 2003b; Kivaria et al., 2007; Banda et al., 2011) with management regimes mostly involving family labour which is sometimes integrated with hired labour and use of feeding stalls, concentrates and disease control (Otte & Chilonda 2003; Mekonnen et al., 2006). Based on International Farm Comparison Network (IFCN) estimates, countries where LPS systems dominate have an average dairy herd size of more than 50 cows with a few leading countries having an average above 100 cows (Hemme & Otte, 2010). Table 2.1 below provides a summary of herd sizes, annual milk yield and some inputs from different LPS and SPS systems.

Table 2.1: Characteristics of smallholder and large scale production systems in different countries between 2000 and 2010

Country	Average herd size*	Major breeds	Farm size (ha)	Family labour (%)	Milking	Annual milk yield kg/cow
Smallholder systems						
Uganda	2	Local dairy			Hand	800
Malawi	2	Holstein Crossbreeds	-	90	Hand	2,500
Kenya	3	Holstein Crossbreeds	3.5		Hand	2600
Thailand	20	Holstein	2.1	-	Machine	1,620
Peru	6	Local dairy	7.6	100	Hand	1,850
Large scale systems						
Malawi	60	Holstein/Jersey	-	-	Machine	3,381
Kenya	100	Holstein/Jersey	-	-	-	3,911
New Zealand	315	Holstein /Jersey	172		Machine	3,868
Germany	54	Holstein	49	77	Machine	7,387
USA	176	Holstein	-	-	Machine	9314
United Kingdom	117	Holstein/Ayrshire	100	63	Machine	5,602
Denmark	123	Holstein	95	53	Machine	8,278

Data Source: Chagunda et al., (2004); Msiska et al., (2005) Hemme & Otte (2010); The Cattle Site (2010); Muia et al., (2011); Tebug et al., (2012); European Commission (2013); Onono et al., (2012); *Number of milking and dry cows

For the purpose of this review SPS farms are defined as farms from developing countries keeping no more than 10 milking cows using zero, semi or free grazing systems. LPS are those farms with annual milk yield per cow of at least 3000 litres, no less than 30 milking cows and using zero, semi or free grazing systems. Zero grazing in this review implies managing cows under permanent housing throughout the year with feed provided as total mixed rations (TMR) or non TMR.

Sub-fertility has been reported in both SPS and LPS systems (Perreira 1999; Lucy, 2003; Lanyasunya 2005; Leroy et al., 2008; Lovendahl et al., 2009; Roche et al., 2009; Bello et al., 2012) and has been a subject of concern in LPS systems for over 30 years (Robinson, 2010) with no apparent consensus on the optimal solution. Low fertility in SPS is associated with inadequate management skills and access to resources (Bebe et al., 2003b; Lanyasunya et al., 2005) while in LPS, it is linked to the complex relationship that exists between fertility and other factors such as milk production, genetic merit, change in genetic merit and management systems (Bello et al., 2012; Mee, 2012). This review will highlight the characteristics of the SPS and LPS then provide and discuss declining cow fertility in relation to other dairy production traits.

2.2 DAIRY PRODUCTION SYSTEMS

2.2.1 Smallholder production systems

Smallholder dairy farms play an integral part in dairy production of many developing countries. Bebe et al. (2003b) reported that smallholder dairy production is the dominant dairy farming system in Sub-Saharan Africa and South Asia. Smallholder farms supply a substantial amount of the milk that is processed in developing countries (Chagunda et al., 2006; Morgan, 2010). The production system is often integrated with crop production and generally involves a few animals (1-5 cattle or buffaloes) on less than 5 ha land holdings

(Devendra, 2001; Morgan, 2010). However the actual numbers are quite variable depending on management systems. SPS management systems in Sub-Saharan Africa include free, semi and zero grazing (Otte & Chilonda 2003; Bebe et al., 2003b; Tebug et al., 2012). These management systems correspond to traditional, extensive, and intensive SPS systems described by Uddin et al., (2010) in Bangladesh. These systems often differ in cow numbers, breeds, milk yield, land area per animal and labour input. Free grazing (traditional) and semi-grazing (extensive) management systems are associated with local breeds and relatively larger land sizes (Uddin et al., 2010; Tebug et al., 2012).

Average SPS herd sizes ranging from 2 to 24 have been reported (Gitau et al., 1994; Bebe et al., 2003b; Kivaria et al., 2007; Banda et al., 2011). Matope et al., (2010) reported a maximum herd size of up to 78 in Zimbabwe although the median was only 14 and the study targeted farms with at least 10 animals. In Malawi an average herd size of 7 was reported with a range of 1 to 25 and over 90% of study population had a herd size of no more than 4 animals (Tebug et al., 2012). These studies indicate a general predominance of small herd sizes in SPS. Breeds are mostly taurine and Zebu x taurine crosses and a few Zebu and the herds are comprised of 60-80% females (Otte & Chilonda 2003; Banda et al., 2011; Tebug et al., 2012). Average farm sizes range from 0.9 to 2.4 ha with the zero grazed systems having the smallest land sizes (Otte & Chilonda 2003; Bebe et al., 2003b). Management regimes mostly involve family labour which is sometimes integrated with hired labour and use of feeding stall, concentrates and disease control (Otte & Chilonda 2003; Mekonnen et al., 2006).

Dairy production has a strong market orientation (Devendra, 2001) although the focus is much broader than just milk input in markets (Bebe et al., 2003a). The system plays an important role in rural livelihoods by contributing to improved socio-economic status of the farmers and acts as insurance for emergency cash needs, elevates social status and improves human nutrition (Bebe et al., 2003a).

Milk productivity varies depending on the breeds used, level of intensification and producer objectives (Bebe et al., 2003a). Lactation milk yields ranging from 1705 to 3094 litres per year have been reported (Thorpe et al., 1994; Msanga et al., 2000; Masama et al., 2003; Msanga & Bryant 2004; Muraguri et al., 2004; Masama et al., 2006). Breeds used are either pure dairy breeds or crosses between pure dairy breeds and local breeds. Productivity seems to be affected by the interaction between genotype and environment as variability in productivity of some breeds has been reported (Chagunda et al., 2004). The production system has multiple challenges that are related to access to resources and management competence. The challenges include inadequate feeding and health management; low fertility, poor access to replacement stock, extension, breeding, health and financial services (Bebe et al., 2003b; Lanyasunya et al., 2005; Chindime, 2008; Banda et al., 2011).

2.2.2 Large-scale production systems

LPS are intensive dairy systems that are common in developed countries and are characterised by high input and productivity with a relatively small number of producers keeping large herds. Average herd sizes and milk production per cow vary between countries. In the United States of America (USA) an average herd size of about 196 and milk yield of about 9900 litres per cow per year were reported in 2013 (NASS, 2014). In 2011/12, Australia reported a herd size of 240 cows producing about 5900 litres per cow per year (DairyAustralia, 2013) while the estimates for the UK were 123 cows and 7604 litres per cow per year (DairyCo, 2013) for the same period, respectively. The high productivity from these systems is associated with high efficiency which is a prerequisite to meet the increasing demand for food (FAO, 2011).

Within large scale intensive systems there are subsystems that have been described. Mee (2012) broadly described the subsystems as pasture based and zero-grazed. The pasture based systems may often involve high stocking rates, intensive rotational grazing and extended grazing season. Characteristics of zero grazed systems include use of total mixed rations (TMR), genetic selection for high milk yield and automated milking. Describing the UK dairy systems, The Dairy Site (2010) outlined similar subsystems and slight variation in the names. The zero-grazed systems were described as the housed systems while the pasture based systems were further subdivided into grass-based and extensive grazed systems. The grass-based systems only house the cows in winter while extensive systems keep the cows outdoors almost throughout the year except during severe weather. The latter system is less common. Stafford & Gregory (2008) and March et al., (2013) reported a link between increasing herd sizes, housing and use of TMR which are all associated with increased capital, productivity and production efficiency. Another factor supporting increase in housed or confinement systems is land availability as a limiting factor (O'Brien et al., 2012). The grass based and extensive systems are more traditional and are associated with relatively lower herd sizes and input (March et al., 2013).

Large scale intensive systems also have challenges, the major challenges being declining fertility, animal welfare and greenhouse gas emissions (Dillon et al., 2006; Mee, 2012). The focus of the production system is to reduce cost of production and improve efficiency while ensuring sustainable environment and animal welfare (Dillon et al., 2006). Among the strategies to improve efficiency is breeding dairy animals to improve genetic merit for milk production (Dillon et al., 2006), increasing milk production per cow and herd sizes (Mee, 2012). This resulted in tremendous increase in total milk production and milk production per cow. FAO (2013) data illustrate a huge difference in the increase rate of world milk production between the past two decades. The increase between 1991 and 2001 was 6% while it rose to 22% between and 2001 and 2011. These data indicate a more rapid increase in the latter decade which is linked to economic growth, demand for milk and technological advancement (Gerosa & Skoet, 2012).

The rapid increase in world milk production is also reflected in milk yield per cow per year in different countries. Yield per cow per year increased from about 3700, 5800 and 7000 litres in 1996 to about 4100, 7100 and 8400 litres in 2005 in New Zealand, Germany and USA, respectively (Hemme & Otte, 2010). This was an increase of about 11, 22 and 20%, respectively. About 19% increase in milk yield per cow was reported in the UK between 1993 and 2007 (Table 2.2).

Table 2.2: Fertility trends in the United Kingdom

	1993	2002	2005	2007	Target
Herd size	109	121	130	144	-
Milk yield kg/cow	5974	7138	7705	7648	-
Heat detection rate (%)	71	57	46	45	75 – 80
Days to first service	71	95	99	101	60
Conception rate (%)	45	40	39	37	45 – 50
Calving index (days)	382	411	420	425	380

Source: Robinson (2010)

Recent UK data show that the number of farmers and cows has been decreasing over the past decade. However, this is not reflected in dairy productivity as average milk yield and herd size continued to increase over the same period (DairyCo, 2013). The increase in milk yield has coincided with a decline in fertility traits such as heat detection and conception rate (Table 2.2). Studies suggest that the high milk yield has contributed to declining fertility and health (Buckley et al., 2003). The decline is attributed to feed intake particularly after calving not being able to meet the high energy demand for milk production and resultant negative energy balance. Despite efforts over the past years to tackle declining fertility, the challenge has remained and has been designated a ‘wicked problem’ (Mee, 2012). Associations of fertility and other production factors show that declining fertility is a multifactoral challenge further complicated by differences in measurements and statistical analysis methods used (Bello et al., 2012). Therefore there is need for a more thorough understanding of the complexity of the problem involving multidisciplinary and systems approaches to develop appropriate mechanisms to derive optimal solutions to the problem.

2.3 FERTILITY RELATED TO OTHER PRODUCTION TRAITS IN DEVELOPED COUNTRIES

Fertility is defined in several ways that commonly address the ability of a given cow to get pregnant. The trait has two components. The first part deals with the cow cycling and showing oestrus and the second part relates to conception and the maintenance of pregnancy following insemination (Lovendahl & Chagunda, 2010). Fertility traits can be expressed in many ways including interval from parturition to rebreeding (days open), calving interval, number of services per conception, conception and pregnancy rates, days to post-partum commencement of luteal activity and duration of first post-partum luteal phase. These traits determine the regular production of calves which in turn determines profitable lactations in dairy cattle (Royal et al., 2008). Subsequent reproduction after calving starts with involution of the uterus followed by resumption of cycling. Resumption of cycling requires the growth of ovarian follicles that enclose viable oocytes leading to oestrus, ovulation, fertilisation, conception, growth and development of viable foetuses. Disturbance of any of these stages of reproduction results in poor fertility (Leroy et al., 2008).

Declining fertility has been a subject of concern for quite a long time and Bello et al., (2012) cited discussion of the problem in the USA as early as 1929. Fertility is particularly a challenge in high yielding cows due to genetic merit, nutritional management that is optimised towards lactation and therefore increases the risk of ovarian dysfunction (Wiltbank et al., 2002; Lo´pez-Gatius, 2003; Leroy et al., 2008;). Physiologically, milk production tends to be favoured over fertility in early lactation which leads to nutrient prioritization (Lucy, 2003; Leroy et al., 2010a) and where nutrients are scarce the dam invests in existing offspring survival rather than in preparing for a new offspring (Silvia, 2003). Prioritisation of nutrients towards milk production in high yielding cows extends beyond early lactation (Leroy et al., 2010a). Early lactation covers the period between parturition and 70 days in milk according to Chiba (2009).

Pollot & Coffey (2008) reported increased time taken to start luteal activity post-partum and hence more days to first heat in high genetic merit cows. Leroy et al. (2010a) reported that the negative association between milk yield and fertility in high yielding cows is due to the regulation of somatotrophic axis, a mechanism that regulates nutrient distribution in the body. The mechanism affects the reproductive system at various levels of hormonal regulation in the hypothalamus, anterior pituitary and the ovaries. The hypothalamus produces releasing hormones that regulate production of both somatotrophin and gonadotrophins as well as integrates appetite, oestrous behaviour and sensing nutrient availability. It is suggested that stimulation of somatotrophin inhibits the production of gonadotrophin releasing hormone (GnRH) and subsequent luteinizing hormone (LH) production in the pituitary thereby reducing follicular development in the ovaries Leroy et al. (2010a).

Ovarian follicle growth and development is influenced by insulin, Insulin-like Growth Factor 1 (IGF-1), leptin and non-esterified fatty acids (NEFA) concentrations (Lucy, 2000; Leroy et al., 2010a) among other factors. Insulin, IGF-1 and leptin stimulate steroidogenesis and follicular development (Boelhauve et al., 2005; Walsh et al., 2011) and are in low levels during negative energy balance (Wathes et al., 2007; Lucy, 2008; Wathes, 2012) thereby leading to reduced follicular development. IGF-1 also works synergistically with LH to influence follicular development (Lucy, 2000) hence follicular development is reduced when both LH and IGF-1 are in low concentration. NEFA are associated with negative energy balance (NEB) and have a negative effect on follicular growth (Vanholder et al., 2006).

2.3.1 Nutrition

Several factors affect fertility and among the principal factors is nutrition (Webb et al., 2004; Robinson et al., 2006; Ashworth et al., 2009). Nutrition affects many other factors that are also associated with fertility such as body condition scores (Roche et al., 2009), milk yield and composition (Friggens et al. 2007), metabolites and hormone concentrations (McDougall et al., 2005). Different studies report these associations and the results vary in some cases depending on difference in the timing of the measurements as well as statistical methods used (Friggens et al., 2010; Bello et al., 2012).

Animal nutrition directly and indirectly influences fertility through provision of nutrients required in the reproductive processes and its effect on hormones and other metabolites involved (Robinson et al., 2006). The effects of nutrition on reproduction start right from foetal life and continue throughout the lifetime of an animal with variations between species (Rhind, 2004). Gender differences in the response to nutrition have also been reported (Micke et al., 2010; Rae et al., 2002).

Several studies have demonstrated the effects of *in utero* nutrition on subsequent fertility of both the dam and offspring (Rae et al., 2002; Zambrano et al., 2005; Ashworth et al., 2009; Micke et al., 2010;). Rae et al. (2002) showed the effects of under-nutrition in ewes fed diets with either 100% or 50% of metabolisable energy required from mating until 95 days gestation. Under-nutrition resulted in reduced ovulation rate in female progeny while it had no effect on male progeny. Zambrano et al. (2005) reported delayed sexual maturation in male progeny of rats that had diets with restricted protein (10% casein) compared to control diets (20% casein). The delayed sexual maturation was characterised by delayed testicular descent, reduced testis weight and sperm count.

Micke et al. (2010) demonstrated that foetal growth in beef cattle is affected by maternal nutrition as early as day 39 of gestation. Compensatory foetal growth or preferential tissue growth occurred depending on further nutrient availability. On preferential growth, some foetal body parts had slow growth trajectory with gender differences in the response. Foetuses from low maternal nutrient intake were associated with decreased crown-rump length, increased thoracic diameter and reduced umbilical cord diameter compared to those from high maternal nutrient intake. Micke et al. (2010) further demonstrated that maternal over and under-nutrition during early and mid-gestation resulted in perturbations in foetal development followed by alterations in post-natal growth, pathway metabolism and body composition. However, in dairy cow production, Pryce et al. (2002)

found no evidence to link maternal nutrition to daughter reproductive performance in Holstein cows. There was no difference in the age at first service, number of services per conception and conception rate to first service in first lactation offspring of cows fed either high or low concentrate diets. Similarly, Banos et al., (2007) found no significant effect of dam milk yield on body condition score, fertility, and milk yield in first lactation offspring. This was attributed to the fact that the variation in the nutritional status of dams not being large enough to affect daughter reproductive performance. Other experiments that had profound effects of maternal nutrition (Rae et al., 2002; Zambrano et al., 2005; Micke et al., 2010) often had relatively larger differences in quantities or quality of the feeds used. Bach (2011) suggested that the lack of an association between milk production and long-term effects on offspring found in studies could be because the long term effects are due to differences in metabolic environments at which milk production levels occur in the dam rather than just milk yield. These metabolic environments could be negative, neutral or positive nutrient balances and it is these balances that would influence changes in the performance of the offspring.

Nutrition has been reported to affect ovarian follicle size, oocyte maturation, embryo survival and cyclicity following calving (Bossis et al., 1999; Webb et al., 2004; Adamiak et al., 2005; Robinson et al., 2006; Aguillar-Perez et al., 2009). Energy supplementation resulted in increased ovulation and behavioural oestrus rates while elevated insulin levels resulted in reduced interval from calving to first insemination (Table 2.3).

Table 2.3: Effect of nutrition on fertility traits

Reproductive trait		Nutritional treatment	Source
Interval from calving to first ovulation (days)	54	Low insulin	Webb et al. (2004)
	41	High insulin	
Observed post calving behavioural oestrus (%)	39	No energy supplementation	Aguilar-Perez et al. (2009)
	74	Energy supplementation	
Ovulation (%)	30	No energy supplementation	
	58	Energy supplementation	
Dominant follicle diameter (mm)	11.8	Maintenance metabolisable energy	Adamiak et al. (2005)
	13.8	Twice maintenance metabolisable energy	
Number of large follicles (diameter >8 mm)	0.7	Maintenance metabolisable energy	
	1.5	Twice maintenance metabolisable energy	

These studies generally showed that nutritional management has specific effects at various stages of reproductive development and subsequent reproductive success. Encompassed within nutritional management is consideration of availability of specific nutrients in the diets. Different nutrients are reported to directly or indirectly affect the efficiency of the reproductive process and overall fertility (Lucy, 2003; Garnsworthy et al., 2009). Energy balance, protein, starch, fat and fatty acid content have been shown to have specific effects on reproduction (Boken et al., 2005;Chagas et al., 2007; Garnsworthy et al., 2008a; Garnsworthy et al., 2008b; Garnsworthy et al., 2008c; Aguilar-Perez et al., 2009). This review will focus on energy balance as one of the major factors having profound effect on fertility.

2.3.2 Energy Balance

Negative energy balance (NEB) begins a few days before calving and extends until 10-12 weeks post-partum with nadir NEB occurring at about 14 days postpartum (Butler, 2003). NEB has negative effects on ovarian activity (Diskin et al., 2003; Friggens & Chagunda, 2005; Chagas et al., 2007; Leroy, et al., 2008; Aguilar-Perez et al., 2009) resulting in reduced conception rates at first insemination with the probability of pregnancy increasing with oestrus number. The negative effects were linked to inadequate mobilisation of nutrients for follicular growth, conception and pregnancy recognition (Murphy et al., 1991; Diskin et al., 2003; McDougall et al., 2005; Aguilar-Perez et al., 2009). There are physiological mechanisms linked to nutrition that control these responses and they include reproductive hormones, growth factors and other metabolites (Webb et al., 2004).

Leroy et al. (2008) reported the link between energy balance and the requirements of a gravid uterus as well as energy demand after parturition. The nutrient requirements of a gravid uterus in late gestation increases and after parturition there is additional demand for glucose, fatty acids and protein for milk synthesis. This results in a cow being unable to compensate for the increased energy demand by increasing feed intake. Instead the energy demand is provided by mobilisation of nutrients from body tissue, leading to NEB. This is considered as an adaptive mechanism (Friggens et al., 2010) and the body tissue is replenished when energy balance becomes positive. Friggens et al. (2010) argued that if this occurs naturally then it could be plausible that fertility may not be affected.

Energy balance may not be directly measurable on farm but is usually monitored through body condition scoring (Roche et al., 2009; Friggens et al., 2010). The NEB that occurs during early lactation is also reflected through body condition score (BCS) loss (Pryce et al., 2001). Low BCS are also related to high concentrations of NEFA because as the animal mobilises energy from stored body lipids, the lipids are available in circulation as NEFA (Westwood et al., 2002). Buckley et al. (2003) and Westwood et al. (2002) reported a negative association between BCS and reproductive performance in agreement with the effects of NEB. In addition Domecq et al. (1997) reported that energy balance during the dry period and early lactation was a more important factor to first insemination conception than health disorders and other risk factors. Change in BCS has also been shown to be important in oocyte quality and embryo development. Adamiak et al. (2005) demonstrated that high level of feeding had a positive effect on blastocyst yield in heifers of low BCS while it had a negative effect in heifers of moderately high (3.5) BCS. Moderately fat heifers on high level of feeding tended to be hyperinsulinemic and this impaired oocyte quality. Lopez-Gatius et al. (2003) also reported an increase in days open that was associated with post calving loss of over 1 BCS unit.

The effects of NEB on oocyte quality and lactational anoestrus are explained through endocrine regulation. During late gestation and early lactation there is switching from lipogenesis to lipolysis which reduces insulin secretion.

Energy balance can be estimated based on body weight and BCS (NRC, 2001; Banos, et al., 2006) or based on the differences between energy intake and energy requirements for maintenance and milk production (Patton et al., 2007; Aguilar-Perez et al., 2009). Proxy measures such as BCS are useful for quick on farm assessment; however, estimates of actual energy balance are necessary for a better understanding of physiological changes.

2.3.3 Milk yield

Milk production has been negatively correlated to fertility using various measures of both milk yield and fertility. Milk yield traits used include overall lactation yields, initial yield, milk yield on day 56, peak milk yield, lactation curve shape, fat corrected milk, mature equivalent milk yield, milk fat content, milk protein content, milk fat and protein ratio. Table 2.4 shows some fertility measures that have been related to milk yield which include days open, number of services per conception, first service conception rate and days to commencement of luteal activity (Berger et al., 1981; Castillo-Juarez et al., 2000; Pryce et al., 2004; Inchaisri et al., 2010; Andersen et al., 2011). The general trend has been a negative relationship between milk yield and fertility despite differences in measures and metabolic requirements at different lactation stages considered in different studies. Some studies were unable to establish a relationship between milk yield and fertility traits (Patton et al., 2007).

Studies that associated the negative correlation between milk yield and fertility to NEB which occurs due to dry matter intake (DMI) not matching the nutritional demand during early lactation (Mackey et al., 2007; Patton et al., 2007). Patton et al., (2007) reported that dry matter intake (DMI) is the primary component of energy balance that affects reproduction. This is because DMI is reported to account for about 50% of milk yield response to selection with additional nutrient support for milk synthesis provided by increased mobilization of reserves from body tissue (Veerkamp, 1998). During early lactation DMI does not match the energy demand and resulting in NEB as the animal mobilises nutrients from body tissue. The effects of NEB on milk yield and fertility have been demonstrated both genotypically and phenotypically (Westwood et al., 2000; Pryce et al., 2004).

Table 2.4: Milk yield traits associated with fertility

Milk yield trait	Reproductive trait	Correlation	Source
Yield	Calving interval	0.22 to 0.59	Campos et al., 1994; Hoekstra et al.,1994; Grosshans et al., 1997; Pryce et al., 1997; Kadarmideen et al., 2000;
	Days open	0.16 to 0.64	Van Arendonk et al., 1989; Bagnato and Oltenacu, 1994; Campos et al., 1994; Poso and Mantysaari, 1996; Grosshans et al., 1997; Dematawewa and Berger, 1998;
	days to first service	0.22 to 0.44	Pryce et al., 1997; Kadarmideen et al., 2000;
	conception rate to first service	-0.62	Kadarmideen et al., 2000
Peak milk yield	Days to commencement of luteal activity	0.36	Royal et al., 2002
mature-equivalent milk yield	First service conception rate	−0.3 to −0.4	Castillo-Juarez et al.,2000

Increased milk yield and the corresponding metabolic demand are positively correlated to increased postpartum anoestrus intervals and inconsistent oestrous cycles (Lucy, 2003; Friggens & Chagunda, 2005). Andersen et al. (2011) reported that cows with high milk yield at start of lactation and a lactation curve with a relatively flat slope had longer calving to conception intervals. A steep ascending slope in the lactation curve was thought to suggest adequate energy that enabled resumption of ovarian activity. Inchaisiri et al. (2010) also reported similar results where reduced first insemination success was associated with insemination before peak milk yield and high milk yield. A short interval from calving to first insemination (<60 days in milk) also had negative effect on success rate of first insemination in high yielding cows.

The prolonged calving to insemination intervals associated with high milk yield in some studies could be due to a combination of managerial and biological effects (Andersen et al., 2011). Managerial effects may include deliberate decisions on early or delayed inseminations depending on animal productivity. Biological effects are reflected by the relationship between fertility and milk yield traits such as the shape of the lactation curve and early milk yield. This shape of the lactation curve is directly related to milk yield acceleration which is a milk yield trait that has been suggested to give an indication of the physiological stress exerted by increase in milk yield over time (Ingvarsten et al., 2003; Hansen et al., 2005). Milk yield acceleration measures the increase rate of milk yield for each period and could more accurately indicate early lactation biological changes (Domecq et al., 1997) hence it is an appropriate risk factor indicator for reproductive problems (Hansen et al., 2005).

2.4 MEASUREMENT OF FERTILITY

There are numerous traits that are used to determine fertility and Royal et al. (2000) summed the traits into two traditional and endocrine or physiological traits. Traditional traits often measure the post-partum duration, or rates of occurrence of activities such as insemination, conception, pregnancy and next calving. Such traits are highly influenced by management decisions despite some underlying biological influences. Endocrine or physiological traits indicate occurrence of specific physiological events such as ovulation, formation and lifespan of the corpus luteum, stage of the oestrous cycle, as well as conception. Determination of endocrine traits may involve measurement of the concentration of specific hormones and/or metabolites or direct observation or palpation of the reproductive system using endoscopy or ultrasound scans. Endocrine traits are not likely to be influenced by management decisions (Royal et al., 2000) but, they are relatively more expensive to measure than traditional fertility traits.

Oestrus is among the fertility indicators that are routinely measured using both endocrine and traditional measurements. Endocrine measurements are done through relating oestrus to commencement of luteal activity (CLA). Luteal activity is the time when the concentration of progesterone in plasma or milk exceeds a threshold of 3ng/ml (Bulman & Lamming 1978). CLA is determined by measurement of progesterone profiles (Lovendahl & Chagunda, 2010).

Traditionally oestrus is detected through visual observations, tail paint and accelerometers (Firk et al., 2002; Lovendahl & Chagunda, 2010; Palmer et al., 2010). Measurements from accelerometers can be stored on the devices or transmitted to computers using radiotelemetry. Lovendahl & Chagunda (2010) reported an agreement between CLA, accelerometers (Alpro, version 6.60) and visual based measurements. Similarly, Palmer et al. (2010) reported no significant difference in the efficiency and accuracy of standing oestrus detection between radiotelemetry (HeatWatch), tail paint and visual observations. HeatWatch was however, more accurate in pasture than housed systems. The study also showed significant differences in standing oestrus detection efficiency in animals under grazing systems than zero grazing. Radiotelemetric pedometers have also been demonstrated to be highly efficient in detecting oestrus and predicting ovulation time in black Japanese cows (Yoshioka et al., 2010).

Apart from oestrus detection, accelerometers have been used to study animal behaviour in relation to health and welfare status (O'Callaghan et al., 2003; Barrientos et al, 2011; Rushen & de Paselle 2012, Mackay et al., 2012). O'Callaghan et al., 2003 used accelerometers in early detection of lameness while Barrientos et al., (2011) linked lying behaviours of dairy cows to presence and absence of deep-bedded stalls. Rushen & de Paselle (2012) associated running behaviours of calves to age and management practices such as dehorning and weaning. In these studies, animal behaviour was detected through number of steps per unit time, duration and frequency of standing, walking and lying which the accelerometers measure (Nielsen et al., 2010; Rushen et al., 2011). Accelerometer technology has been accurately used to detect lying behaviour (Munksgaard, et al., 2005, Trenel et al., 2009) as well as duration of standing and walking (Nielsen et al., 2010). In fact the detection of oestrus by these devices is based on their ability to show increased level of activity during oestrus which includes number of steps, lying and other behaviours (Firk et al., 2002).

2.5 FERTILITY TRAITS IN SPS AND LPS

Although challenges in cow fertility are similar between LPS and SPS, the measures mostly reported in developing countries are the traditional fertility traits such as days open, pregnancy rate to first insemination and calving interval (Masama et al. 2003; Masama et al. 2006; Chinyembuga & Mseleko 2009; Yifat et al 2009) while both endocrine and traditional traits are reported in developed countries (Patton et al., 2007; Coleman et al 2009; Inchaisri et al 2011; Sinclair et al. 2013; Buckley et al., 2014). Fewer reports include endocrine traits such as commencement of luteal activity and oocyte development from production systems from developing countries (Aguilar-Perez et al 2009; Mgongo et al 2009). This could be because the traditional methods are relatively easier to measure and less expensive and hence readily used in developing countries. Comparing the traditional traits in developing and developed countries showed that pregnancy rates to first insemination are relatively lower while calving intervals are longer in the former than the latter (Table 2.5). However, there are overlaps on the ranges of these traits.

Table 2.5: Comparison of traditional fertility traits in production systems from developing (tropics) and developed countries (temperate region) between 2000 and 2014

	Developing countries (tropics)		Developed countries (temperate region)	
Trait		Source		Source
Days open	77 - 253	Lobago et al. 2007; Chenyambuga & Mseleka, 2009; Aguillar-Perez et al 2009; Yifat et al., 2009; Lemma & Kabede 2011; Ali et al 2013	79 - 153	Inchaisri et al. 2011; Coleman et al 2009; Sinclair et al. 2013; Buckley et al., 2014
Number of service per conception	1.4 – 2.1	Shiferaw et al. 2003; Yifat et al., 2009; Tadesse et al., 2010; Lemma & Kabede, 2011; Ali et al., 2013	1.4 - 2.1	Pryce et al. 2002; Inchaisri et al. 2011; McCarthy et al. 2012; Sinclair et al. 2013
Pregnancy rate to first insemination (%)	34 - 47	Shiferaw et al. 2003; Mekonnen et al., 2010; Paul et al., 2011	34 - 71	Pryce et al. 2002; Coleman et al 2009; Ferries et al 2014;
Calving interval (days)	387-734	Shiferaw et al., 2003; Masama et al., 2003; Swai et al., 2007; Lobago et al., 2007; Abraha et al., 2009; Chenyambuga & Mseleka, 2009; Yifat et al 2009)	367 - 475	Pryce et al. 2002; Evans et al. 2006; Coleman et al 2009; Inchaisri et al. 2011; Azevedo et al. 2014.

Number of services per conception were within similar ranges while the range for days open was much wider in production systems from developing countries. The differences in the traits reflect differences in management, breeds, lactation, availability of resources and the production environment.

2.6 SUMMARY

Declining dairy cattle fertility is a challenge across production systems, breeds and regions. However, there are variations in the magnitude of fertility decline and methodologies for assessment. Differences in underlying factors are also apparent between smallholder production systems that are prevalent in developing countries and the large scale intensive systems in developed countries. Declining fertility in smallholder systems is more associated with inadequate feeding, health and management skills while in intensive production systems it is more associated with the negative correlation between high milk yield and fertility that is further complicated by confounding factors and analysis tools. Hence an optimal solution for the challenge of declining fertility requires appreciation of the complex link between fertility and factors such as milk production and management in order to optimise dairy productivity. Appropriate interventions would need a multi-disciplinary approach involving appropriate expertise and resources across production systems.

Generally there is a strong association demonstrated between body energy reserves, milk yield and cow fertility. Body condition score (BCS) is generally recognised to provide a measure of the body energy reserves. Low BCS during late gestation and early lactation is associated with delayed resumption of cycling which could reduce chances of subsequent reproductive success. Hence adequate body energy reserves within production systems are critical for successful dairy production.

Different measures of cow fertility exist, some of which are proxy while others measure the actual physiological changes in the body. The measures have been used widely with no conflicting results although measures of actual physiological status are more accurate. Use of such measures is often limited by availability of resources and hence the use of proxy measures is more dominant. Electronic equipment for measuring fertility such as accelerometers can also be used to measure other important animal behaviour traits in dairy production which could further help to identify other productivity risk indicators.

CHAPTER 3: DESCRIPTION OF STUDY PRODUCTION SYSTEMS

3.1 INTRODUCTION

Dairy production in many countries is undertaken as part of mixed crop livestock systems, intensive or extensive production systems. These production systems vary from one region to another and can either be large or small scale. Systems that are focused on one type of farming predominate in developed countries such as the United Kingdom (EFSA, 2009) while mixed production systems predominate in developing countries such as Malawi. A description of the UK dairy systems shows that the intensive systems encompass housed or zero-grazed systems while the extensive systems are pasture based. The pasture based systems are further subdivided into grass-based and extensive grazed systems. The grass-based systems only house the cows in winter while extensive systems keep the cows outdoors for most of the year. There are very few dairy farmers (less than 1%) that practice the extensive system in the UK (March et al., 2013).

Dairy production in Malawi is mostly undertaken by smallholder farmers keeping 1 – 2 cows with crop production as their primary livelihood source. Small scale dairy systems produce about 80% of the milk that is supplied to processors. There are also large scale semi-intensive farms with about 5% of the dairy cattle population. Low and/or declining fertility is a common challenge across many production systems. This study sought to understand the management systems in relation to dairy cow fertility in small scale farms, a research farm and one large scale semi-intensive farm in Malawi as well as one research farm in the UK. This chapter provides a description of the management systems in the farms under study.

3.2 MATERIALS AND METHODS

3.2.1 Dairy farm in the United Kingdom

The UK farm studied was the Langhill herd based at Scotland's Rural College (SRUC) Dairy Research Centre in Dumfries. The herd comprised cows that were under either grass based or zero grazed (housed) systems. A description of the production systems and management of cows was obtained from literature and key informant interviews with staff at the farm between January 2011 and July 2013.

3.2.2 Dairy farms in Malawi

A baseline survey was undertaken in Malawi between January and February 2012 to obtain descriptions of dairy cow feeding, breeding, health and housing management in smallholder dairy farms in Lilongwe Agricultural Development Division (ADD). Key informant interviews were held with farm staff at Bunda Dairy Farm and Mapanga Dairy Farm between November 2011 and September 2012 to obtain information on management of the farms. Bunda Dairy Farm is a research farm for students and staff in the Department of Animal Science at Bunda College, Lilongwe University of Agriculture and Natural Resources (LUANAR, formerly under University of Malawi). Mapanga Dairy Farm is a large scale semi intensive farm based in Zomba, Malawi.

The baseline survey was undertaken in four milk bulking groups (MBGs) namely Lumbadzi, Machite, Dzaonewekha and Chitsanzo within Lilongwe ADD in the Central region of Malawi. MBGs are a collection of smallholder dairy farmers that bulk and store milk produced from their farms in one place. The place has milk cooling and storage facilities and it is the centre from which dairy processors buy and collect milk from the farmers. The farmers deliver milk either once or twice a day and travel distances between 5 and 10 km. Milk from individual farms is first tested for adulteration and contamination before being bulked. The MBGs are run by leadership elected from members with support from government extension workers, NGOs and regional milk producers associations. The farmers also access health, breeding and extension services through the MBGs.

The baseline survey was carried out to determine background information on practices in dairy management in the study area. Individual household interviews were conducted using structured questionnaires (Appendix 1) that were administered to dairy farming households by trained enumerators. The design and formulation of questions in the questionnaire was guided by the objectives of the survey. The questions were designed by taking into account the information required and the nature of target respondents that were either literate or illiterate. The question contents and wording were such that they were in a meaningful order and format. The questions were easy to answer, precise and seeking one piece of information per question. Most of the questions were closed with possible answers coded and included in the questionnaires. The enumerators only entered codes in spaces provided in the questionnaire as responses were given during the interview. The questionnaire also had room to include additional responses that were note coded for.

The enumerators involved in the study were those with previous experience in survey data collection. Training of the enumerators involved a two day session where the purpose of the survey was explained and all the questions were explained and discussed. Details on how the enumerators would introduce themselves, seek farmer consent and ask each question in the local language

(Chichewa) were discussed. Following the training, the questionnaire was pre-tested in one village and further discussions were made on the time taken to administer the questionnaire, ease of understanding the questions and the flow of questions. Adjustments were made to the questionnaire based on the discussions and recommendations from pre-testing.

The questionnaires included questions on demographic characteristics of the farmers, management practices in breeding, record keeping, feeding, housing, health and milk production. Demographic characteristics included the gender, age and education level of the farmers. Access to services and challenges faced in dairy production were also investigated as they affect the extent to which farmers follow the recommended husbandry practices. The data were collected to identify key demographic characteristics, husbandry practices and services that influence cow productivity.

Data from the baseline survey were analysed using frequencies, crosstabs and descriptive statistics. Frequencies were generated on demographic data such as marital status, education level and occupation as well as dairy production data including breeds used, insemination methods, record keeping, animal housing, feeding and health practices. Crosstabs generated included those between location of farms and availability of services and husbandry practices in place. Descriptive statistics were generated for numeric data such as age, household size, cost of services, number of animals, milk yield, amount of feed and fertility traits. Chi-square at $p=0.05$ was used to determine if there were any significant differences in proportions of farms with various age, gender, education categories; involved in particular feeding, housing, breeding and health management practices; and accessing breeding, health and extension services.

3.2.3 Typical weather in the study areas

The climate in the UK is temperate with four distinct seasons – summer, autumn, winter and spring. SRUC Dairy Research Centre is in West Scotland and the average monthly rainfall and temperatures between 1981 and 2010 are given in Table 3.1. The data from UK Meteorological Office show the area had an average annual rainfall of 1251 mm and minimum and maximum temperatures of 4.8 and 11.3°C, respectively.

Table 3.1: Mean temperatures and rainfall for West Scotland between 1981 to 2010

Month	Max Temp (°C)	Min Temp (°C)	Rainfall (mm)	Days of Rainfall ≥ 1mm (days)
Jan	5.8	0.7	38.5	19.1
Feb	6.0	0.6	64.7	15.1
Mar	7.8	1.6	92.1	17.4
Apr	10.4	3.0	142.3	13.5
May	13.8	5.4	187.9	12.8
Jun	15.9	8.1	160.4	13.0
Jul	17.5	10.1	150.2	14.5
Aug	17.1	10.0	143.7	15.3
Sep	14.8	8.1	108.5	15.7
Oct	11.6	5.6	78.2	18.8
Nov	8.4	3.0	50.4	18.3
Dec	6.2	0.8	34.1	17.6
Year	11.3	4.8	1251.1	191.1

Source: http://www.metoffice.gov.uk/climate/uk/averages/19812010/areal/scotland_w.html retrieved on 28 January 2014

The climate in Malawi is sub-tropical which has three distinct seasons, namely warm-wet, cool-dry and hot-dry seasons. The warm-wet season is from November to April, during which the country receives about 95% of the annual rainfall. Annual average rainfall ranges from 725mm to 2,500 mm with Lilongwe and Zomba averaging 900 and 1,433 mm, respectively. The cool-dry season is from May to August where mean temperatures range from 17 to 27 ^{o}C and minimum temperatures range from 4 to 10 ^{o}C. Frost also occurs in some areas in June and July. The hot-dry season is between September and October with average temperatures of 25 - 37 ^{o}C. Relative humidity is about 50% in the hot dry season while it increases to about 87% in the cool wet season.

3.3 RESULTS

3.3.1 Characteristics of dairy herds and farms

The Langhill herd is managed by SRUC Dairy Research Centre as a single farm consisting of Holstein Friesian cattle from two genetic lines (Select and Control) selected on the basis of genetic merit for kilograms milk fat plus protein. This genetic selection project was started in the early 1970s. The Select (S) group cows were bred by artificial insemination (AI) from sires with high predicted transmitting abilities (PTA) for fat plus protein yield, whereas the Control (C) cows were bred by sires of UK average merit for fat plus protein (Pryce et al., 1999). The cattle were moved from Edinburgh to the SRUC Dairy Research Centre in 2002 and managed as one group, for six months. After six months the cattle were allocated to pairs on the basis of genetic line, lactation number, calving date, milk yield, live weight and previous experimental treatment. Animals were then allocated within pairs to two different feeding systems, a low forage system (LF) and a high forage system (HF). There were four experimental groups, two systems and within each system two genetic lines. The cattle were managed on the two feeding systems from July 2003 to August 2011 and the experimental monitoring started in April 2004 after nine months adaptation to the systems.

The feeding system was changed in September 2011 (Roberts & March 2013). Cows on the HF system were all transferred to a home grown (HG) feeding system where all feed was grown on the farm while cows that were on low forage system were transferred to a feeding system based on by-products (BP). Cows on BP feeds were housed throughout the year while those on HG feeds were only housed in winter under management corresponding to LF and HF systems, respectively. There was a slight difference between HG and HF cows in that HG cows were housed overnight including in summer whereas HF cows grazed throughout spring, summer and autumn.

Calves and young stock were reared under one management system and heifers from each genetic line were allocated to experimental systems one month before calving. The cows were transferred out of the system study at the end of their third lactation provided a first lactation heifer was available to maintain group size at approximately 50.

Bunda Dairy Farm is a research farm as well part of a dairy learning centre for students and farmers. It is part of the Animal Science Department Students Farm at Bunda College that keeps various livestock including pigs, goats, rabbits, poultry and beef cattle. At the time of the study the dairy unit had a herd of about 50 young and adult dairy cattle of which 14 cows were lactating. The breeds kept were Holstein Friesians, crosses between Holstein Friesians and the Malawi Zebu and a few Jersey bulls. The farm also kept some local female

Malawi Zebu cows that served as the dam line for crossbreeding with the exotic breeds.

Mapanga Dairy Farm is a commercial farm operating as a constituent of Global Tea & Commodities Ltd. The farm was established in the early 1960s as part of Colonial Development Corporation and later managed under Malawi Young Pioneers (MYP) as a Government farm. After structural adjustment the farm was privatised under Sable Farming Company Ltd, a subsidiary of Global Tea & Commodities Ltd. As of September 2012, the dairy herd comprised 291 Holstein Friesians young stock and adult cattle of which 100 and 41 were milking and dry cows, respectively. The farm is headed by a farm manager working with support staff such as herdsmen and milkers.

The operations and set up of smallholder farms in Malawi were different from that of the Langhill herd and Mapanga Dairy Farm. The farms studied comprised small herds averaging 2.7±1.4 animals from a total of 67 households from four different milk bulking groups (MBGs). The MBGs were Lumbadzi (22%), Machite (33%), Dzaonewekha (15%) and Chitsanzo (30%) MBGs in Lilongwe ADD. There was no significant difference ($p>0.05$) between MBGs in any of the variables studied therefore all data were analysed as one population. The farms were run by both male and female headed households with the majority (82%) being male headed. Although male headed households were more prevalent, the dairy farmers were mostly (57%) female. There were also variations in the education level and ages of farmers involved. The education levels were up to primary (58%), secondary (16%) or tertiary (1%) education meaning that about 75% of the dairy farmers interviewed were literate. Their age ranged from 22 to 82 years with an average of 48 years (Table 3.1) showing that most dairy farmers were middle aged. There were also variations in the number of years of involvement in dairy production.

Table 3.1: Characteristics of smallholder dairy farms in Lilongwe Agricultural Development Division

Variable (n=67)	Mean±SD
Age of farmer (years)	48±14
Household size	6.1±1.9
Total number of dairy animals	2.7±1.4
Number of cows	1.2±0.6
Number of years in dairy farming	6.1±7.4

The average household size was 6 and higher than the national average household size of 4.8 (NSO, 2012) but consistent with that of the households dominating the lowest consumption quintile. Generally all farmers spent a considerable amount of their time on growing crops for home consumption. However, dairy production was a primary occupation for a relatively high (63%) proportion of the farmers followed by crop production (34%). Farmers with dairy as their primary occupation had spent relatively more years (7±8.8) in dairy farming than those with crop production (4±3.7) as their primary occupation. This could be because as farmers got more established in dairy production they shifted more of their production to dairy than growing crops for sale.

Most farmers (61%) knew the dairy breeds that they kept while some (39%) did not know. For the farmers that knew the breeds kept, the breeds were Holstein Friesians (82%), Jerseys (8%) or crosses between these breeds and the Malawi Zebu (10%). The animals were mostly (86%) acquired through an in-kind loan while others were obtained through cash loans (8%), as a gift (5%) or own cash

(1%). Most of the loans were provided by a non-governmental organisation; Land O'Lakes (72%) while the rest were from government (4%) and other projects (14%).

The farmers started production with heifers (63%) or cows and 30% of these were pregnant. The loan repayment was largely (93%) through a heifer that was passed on to another beneficiary. Other farmers repaid with cash through instalments deducted from milk sales.

3.3.2 Feeding systems

UK: Four different feeding systems were undertaken with the Langhill herd as part of long term experiments. The first two systems were low and high forage feeding systems which were in operation between September 2003 and August 2011. These systems were then replaced with by-product and home grown feeding systems from September 2011 to date.

Low forage (LF) system

The LF herd was housed throughout the year and fed a complete diet containing the same forages as in the high forage system with a target DM from forage of 50%. The average metabolisable energy (ME) and crude protein (CP) was 12.3 MJ/kg DM and 185g/kg DM, respectively. The diet was altered in August 2005 when ensiled distillers grains were taken out of the ration and replaced with the same dry matter equivalent of purchased feed. Table 3.2 shows the feed ingredients and an average intake of 23.4 kg DM/cow/day.

Table 3.2: Feed ingredients and proportions in rations under low forage feeding system at SRUC Dairy Research Centre

Feed	DM Proportion	kg DM/cow/day
Grass silage	0.28	6.60
Maize silage	0.09	2.20
Wheat alkalage	0.09	2.20
Minerals & vitamins	0.01	0.25
Langhill low forage blend*	0.52	12.20

*The Langhill low forage blend comprised wheat, molassed sugar beet pulp, soya bean meal, wheat distillers grains, soya hulls, megalac, smartamine/sopralin and alkacarb

High forage (HF) system

The cows on the HF system were housed in the winter months and fed a complete diet which consisted of at least 75% of the dry matter (DM) from forages with target ME and CP of 11.5 MJ/kg DM and 180g/kg DM, respectively. Feed ingredients in the ration and an estimated average intake of 21.3 kg DM/cow/day are given in Table 3.3. The cows grazed during the summer when grass height exceeded 5 cm and weather conditions allowed. The cows grazed for three periods each day on perennial ryegrass swards when compressed grass heights exceeded 10 cm. The grazing periods were reduced to two and one period when grass heights fell below 10 and 7 cm, respectively. When the cows were housed for periods of the day during the summer period they were fed a complete diet similar to their winter diet.

Table 3.3: Winter ration for cows under high forage feeding system at SRUC Dairy Research Centre

Feed	DM Proportion	kg DM /cow /day
Maize silage	0.15	3.2
Wheat alkalage	0.15	3.3
Minerals & vitamins	0.01	0.2
Distillers grains	0.07	1.5
Rapeseed meal	0.11	2.3
Barley dark grains	0.06	1.2
Grass silage	0.45	9.6

By-products (BP) feeding system

The target of the system was that cows be fed on ingredients that were not normally used in human diets such that there was no direct land requirement on farm (Roberts & March 2013). The target DM content of the whole ration was about 50%, depending on the DM content of principally the grass silage component; to achieve this water was added at the rate of 10 litres/cow/day. The target content of CP was around 175 g/kg DM, and of ME was 11.3-11.7 MJ/kg DM. The rations were formulated to achieve milk sales of about 11,000 litres /cow / year. The feed ingredients in the ration and estimated daily DM intake are given in Table 3.4.

Table 3.4: Feed ingredients for rations under the by-products feeding system at SRUC Dairy Research Centre

Feed	DM Proportion	kg DM/cow/day
Chopped straw	0.24	5.2
Sugar beet pulp	0.21	4.7
Breakfast cereal	0.13	2.8
Vitagold	0.10	2.1
Soya	0.08	1.8
Biscuit Meal	0.08	1.8
Distillers grains	0.08	1.8
Molasses	0.07	1.5
Protected fat	0.02	0.4

Minerals and vitamins were also included in the ration. Although soya and protected fat may not be considered as by-products; they were included in order to achieve a consistent ration over time and increase the energy content, respectively (Roberts & March 2013).

Home grown (HG) feeding system

The target of the feeding system was that apart from minerals and vitamins, all feed ingredients were grown on farm. The cows were fed a winter ration given in Table 3.5 with an estimated average intake of 15.8 kg DM/cow/day. They grazed during summer and were housed between evening and morning milking and offered a diet based on maize silage and home grown wheat. Where specific feed ingredients were insufficient an appropriate amount was purchased with land allocation extended using the crop yield achieved on the farm. So far the only purchased feeds are field beans. The target milk yields of the feeding system were about 7,000 litres/cow /year.

The cows in all the feeding systems had access to water *ad libitum*. The water was supplied through group drinking troughs when the animals were in the fields or housed and group fed; and through individual water troughs when the animals were housed for individual feeding.

Table 3.5: Winter ration for cows under home-grown feed system at SRUC Dairy Research Centre

Feed	DM Proportion	kg DM /cow /day
Grass silage	0.43	6.8
Beans	0.26	4.1
Wheat	0.16	2.5
Red clover / grass silage	0.10	1.6
Maize silage	0.05	0.8

Source: Roberts & March 2013

During the summer months the cattle were grazed, between morning and evening milking, on perennial ryegrass swards on a daily paddock system.

Bunda Dairy Farm feeding system

The feeding system at Bunda Farm involved use of forage from pastures established on the farm including wild grasses, crop residues, maize silage and concentrates. The pastures comprised centrosema (*Centrosema pubescens*), Lucerne (*Medicago sativa*), Rhodes grass (*Chloris gayana*) and Napier grass (*Pennisetum purpureum*) that were fed in form of hay. Additional forages were also supplied from multi-purpose tree species such as *Leucaena leucocephala* and *Acacia spp* whenever they were available. The crop residues were groundnut haulms and maize stover while the wild grasses were dominated by *Hyperrhania spp* that were also given in form of hay. Concentrates were in form of a ration (dairy mash) comprising maize, maize bran, groundnut cake, salt, mineral and vitamin premix, lime and monocalcium phosphate. The target CP content of the ration was 160 to 180 g/kg DM. Each lactating cow was fed a total 7kg/day of concentrate given during morning and afternoon milking times while forages, mineral blocks and water were available *ad libitum*. The feed, mineral blocks and water were provided in troughs that were accessible to all animals. Fresh forages and water were provided every morning. The forages were mostly provided using the cut and carry feeding system with the cows occasionally grazed when grazing fields had adequate forages. On rare occasions the cows were given maize bran mixed with salt as a concentrate when dairy mash was not available.

The feeding of concentrates targeted milk yield of 25 litres per day for the pure Holsteins. The composition of typical concentrates and forages available at Bunda College are given in Table 3.6. The composition was determined through proximate analysis of samples obtained from Bunda Dairy Farm.

Table 3.6: Feed Composition of some feeds for dairy cows at Bunda Dairy Farm

Composition	Feed type (mean±SD)			
	Grasses	Legumes	Dairy mash	Maize bran
Dry matter (%)	86.2±5.3	91.3±0.6	88.7±1.9	88.3±1.9
Crude protein (g/kg DM)	89±9	197±6	194±26	89±11
Gross Energy (MJ/kg DM)	9.1	-	16.9	14.1
Ash (%)	8.8±0.5	6.7±0.6	8.2±3.2	5.7±0.3

Mapanga Dairy Farm feeding system

The feeding system for the animals at Mapanga Dairy Farm targeted at least 18 litres of milk per cow per day. However, the feeding system in place did not seem to be in line with this target as cows were fed based on how much milk they produced and divided into three feeding groups. The first group comprised cows producing at least 15 litres per day per cow and less than 6 months in lactation. These were referred to as super cows and were fed 18kg of concentrates per day. After some time, based on visually assessed body condition and production, a cow from this group was moved to either the second or third group depending on milk production. The second group (group A) cows produced 10 to 15 litres of milk per day and were supplemented with 10kg of concentrates per day. When milk production and body condition declined the cows were moved to the third group (group B). Group B cows produced less than 10 litres of milk per day and were supplemented with 5kg of concentrates per day per cow. The concentrates were fed to the cows twice per day immediately after morning (3.30 to 6.00 a.m.) and afternoon (2.00 to 5.00 p.m.) milking. The ingredients for concentrates included maize bran, maize meal, rice bran, pigeon peas bran, vitamin and mineral mix, monocalcium phosphate, salt, lime and molasses. The target proportion of CP in the dairy mash was 160 to 180 g/kg DM. The actual proportions of CP and energy content of the concentrates could not be confirmed as the samples that were collected were contaminated in storage while awaiting analysis.

Other supplements such as maize silage and/or hay were provided in the pens. The cows grazed in paddocks between 8.00 a.m. and 1.00 p.m. The pastures were dominated by Kikuyu grass (*Pennisetum clandestinum*) and star grass (*Cynodon nlemfluensis*). There was also some Napier grass (*Pennisetum purpureum*) and Leucaena (*Leucaena leucocephala*) that were rarely used to feed the animals through a cut and carry system. From the grazing field, the cows were confined for one hour and given access to water in readiness for milking between 2.00 pm to 5.00 pm.

Smallholder feeding systems

The feeding systems in smallholder farms in Malawi were different from the practices at the Langhill and Mapanga herds but similar to that of Bunda Dairy Farm. The majority of the smallholder farms used the cut and carry feeding system (96%) while a few used herded grazing with supplementation. Forages in both feeding systems were supplemented with concentrates in form of dairy mash (70%) or maize bran mixed with salt.

Concentrates were given either twice (59%) or three (33%) times a day. Most of the farmers (76%) indicated that they did not measure the amount of supplement given to the animals. For the farmers that measured the feed the average amount was 4±2.5 kg per day. There was no evidence that the farmers adjusted the amount of feed given to the cows over the lactation period to meet the nutritional requirements of the animals. Fluctuations in the quantities fed to the animals were reported and these were associated with feed availability at a particular time.

The type of concentrate fed to the cows was not consistent. Farmers seemed to be aware that dairy mash was a better concentrate than maize bran but apparently affordability determined what they used at a particular time. Dairy mash was bought from a feed compounding company that centrally supplied to the MBG while maize bran was bought from local maize mills. Although the payment for the dairy mash was deducted at the MBG from monthly milk cash earnings, farmers rationalised on purchasing dairy mash in each month. None of the farmers exclusively supplied maize bran as a concentrate. It was established that there were some farmers that fed the cows maize bran most of the time, rather than dairy mash.

Most (97%) farmers had established pastures that included grasses (91%) and legumes (9%) to supply forages to the cows. Grasses included Napier, *Pennisetum purpureum* and Rhodes, *Chloris gayana* grown in 54 and 37% of the farms, respectively. *Leucaena spp* was the major type of legume grown. A few farms (25%) had a combination of these pastures with only 11% of the farms including a legume (Table 3.7).The average pasture plot size was 0.42±0.28 ha with a range of 0.1 to 1.52 ha. The farmers indicated that pastures lasted for 5.7±2.9 months with about 39% of the farmers indicating that the pastures lasted throughout the year.

Table 3.7: Types of forages grown in smallholder dairy farms

Type of forage	Frequency	Percentage of farms (%)
Rhodes grass only	15	23.4
Napier grass only	33	51.6
Rhodes and Napier grass	8	12.5
Leucaena spp, Rhodes and Napier grass	1	1.6
Rhodes grass and *Leucaena spp*	4	6.3
Napier grass and *Leucaena sp*	2	3.2

The pastures were supplemented with conserved feed in form of hay in 98% of the farms. Feeds conserved were mostly crop residues (61%) and wild grasses.

Crop residues included groundnut (*Arachis hypogaea*) haulms, maize (*Zea mays*) stover and cassava (*Manihot esculenta*) leaves and these were conserved in 86, 26 and 5% of the farms, respectively. The wild grasses, often dominated by *Hyparrhenia spp*, were conserved in 74% of the farms. The hay was used in both the dry and wet seasons, with 48% of the farms using hay in the dry season only.

The amount of water given to the animals varied widely depending on the total number of animals available on the farm. The average amount reported was 102 litres per day with the mode and median having the same value of 60 litres. The average total number of animals per farm was 2.7±1.4 with a median and mode of 2, respectively. Calves made up about 50% of the average total number of animals per farm.

At the time of the baseline survey 80% of the farms had water available in the pens and only 63% reported *ad libitum* water supply to the animals. The source of the water was boreholes (77%) protected wells (15%) or unprotected wells (8%) indicating that most farmers provided good quality water.

3.3.3 Housing and hygiene

UK: Cows under low forage and by product feeding systems at SRUC Dairy Research Centre were housed throughout the year. They were housed in cubicles with free access to a concrete loafing area, feeds and water. The housing was cleaned continuously with a scraper. The slurry was collected in tanks where it was stored and treated for use as fertiliser for pastures. HF and HG cows were under similar housing in winter while they were in grazing fields throughout the rest of the year. HG cows only grazed during the day and were housed overnight after the evening milking.

Malawi: The cows at Bunda Dairy Farm were either housed throughout the day when fed using the cut and carry method or only out for grazing between 8.00 am and 2.00 pm. The pens were open concrete sheds roofed with corrugated iron sheets and animals having free access to feed and water. The housing at Mapanga Dairy Farm was open concrete sheds with free access to water and supplementary feed. Cleaning of pens at Bunda and Mapanga was done manually using brooms and shovels on a daily basis. The dung was heaped and composted in open places in readiness for disposal in pasture fields or other crops where it was used as fertiliser.

The housing in smallholder farms was mostly throughout the year and varied in design, construction materials as well as in their hygiene. A few farms housed the cows at night and grazed them during the day. The pen floors were made from mud and concrete (11%); mud only (26%) or bricks (64%) with (9%) or without bedding (91%). Most of the floors (65%) were slanting allowing for proper drainage. However a significant proportion (35%) of farms had pens with poor drainage suggesting the need for creating more awareness on the importance of appropriate housing. Most (88%) pens were adequately roofed with plastic sheets and grass thatch. Only one farmer used iron sheets while another had a pen that was not roofed at all. Feed stores, feed troughs, milk parlours and water troughs were present in 59%, 88%, 94%, and 94% of the farms, respectively.

Hygiene was well maintained in about 76% of the farms but the cleaning frequency varied from one farm to another. Some farms cleaned the pens once a week while others cleaned on daily basis. The dung was stored in open spaces and eventually used as fertiliser in crop gardens.

3.3.4 Management protocol

UK: Strict protocols were operated both within and between systems at SRUC Dairy Research Centre to ensure that cows were allowed to express their own potential. All the cows were milked 3 times a day, housed in the same building and managed by the same staff. Within a system, one complete diet was offered to all cows irrespective of milk yield and stage of lactation. The complete diet was offered at 1.05% of daily requirement and refusals removed daily.

Cows were dried off eight weeks prior to next calving. During the first half of the dry period the cows were fed a straw based diet. Approximately 4 weeks before calving the cows were fed a transition diet which consisted of 30% of the average daily dry matter intake of milking cows of either the LF, HF, BP or HG complete diet plus *ad libitum* chopped straw. Cows were introduced into their appropriate feeding groups approximately 24 hours after calving.

Malawi: A similar protocol was followed at Bunda and Mapanga Dairy Farm with differences in the milking times and transitional diets. The cows were managed as one group and at Mapanga they were only separated into the three feeding groups when fed concentrates. Cow management followed the same routine throughout the year under the same staff and involved milking the cows twice a day, grazing during the day and having them housed at night. At Bunda, the cows were mostly housed throughout the year and fed using the cut and carry feeding system. Cows were dried off 2 months prior to calving and kept in calving pens until they calved. The dry cows were fed 0.5 to 1 kg extra concentrates to the amount they received prior to drying off. The cows joined the feeding groups after about a week from calving.

Smallholder farms also followed some feeding, water supply, milking and housing routines throughout the year. Use of transition diets was not reported and feeding did not take into account daily requirement of the animals. Instead, forages were given *ad libitum* while concentrates were mostly given twice per day. The cows were milked twice a day and the milk was transported to cooling centres within specific MBGs. The cows were housed throughout the day in pens where they had access to feeds, water and loafing areas.

3.3.5 Health Management

UK: Langhill herd management followed strict disease control management where vaccination and routine treatments such as deworming and hoof trimming were followed. There were also on-going checks for mastitis and infected animals were treated accordingly. All vaccinations and treatments were carried out by qualified veterinary surgeons or experienced farm staff. A veterinary surgeon visited the farm on a weekly basis for routine veterinary work, mainly related to fertility. If required, the veterinary surgeon would also visit the farm within an hour to attend to difficult calvings or other urgent veterinary issues. Routine foot-trimming was once every 6 months and cows walked through a footbath containing copper sulphate twice a week. Severely lame animals were lifted as soon as possible by the head dairyman otherwise the veterinary surgeon visited fortnightly and cows locomotion scored 4 and above were walked around an enclosure and those considered lame were lifted and any findings recorded and loaded to the database. The locomotion score was on a scale of 1 to 5. Sick animals were isolated and kept in a sick bay where they received treatment and were returned to the feeding groups upon recovery.

Malawi: Bunda and Mapanga Farms also carried out routine deworming and mastitis checks and treatment. The cows were sprayed with acaricides once every week. Animals identified as sick animals were isolated and treated by government veterinary officers and animal health technicians at Mapanga and Bunda, respectively. It was not clear if any vaccinations were administered.

Smallholder farms did not seem to have any routine treatments and vaccinations but had routine mastitis checks and treatments whenever infected cows were identified. Whenever sick animals were identified health services were accessed through drug revolving schemes operated by government veterinary officers through the MBGs. The major diseases reported in some farms were mastitis (45%) and diarrhoea (23%). Other diseases included Tuberculosis, brucellosis, East Coast Fever and skin-swellings which were reported in 2, 4, 8, and 8% of the farms, respectively. Vaccinations were only carried out when there were government campaigns against specific diseases.

3.3.6 Breeding and mating systems

UK: In the Langhill herd, the animals were rebred using artificial insemination with semen from either select or control sires. The animals were inseminated to the first observed oestrus after a voluntary waiting period of 42 days and if they did not conceive they were served again up to a maximum of seven inseminations before being culled for infertility. Pregnancy diagnosis (PD) was conducted by veterinary surgeons through vaginal ultrasound after about 30 days after the insemination date. Repeat PDs were done whenever there was need to reconfirm pregnancy.

Malawi: Both artificial insemination and bulls were used for breeding at Bunda and Mapanga Farms. Cows were served after a voluntary waiting period of 60 days and rebred whenever they were confirmed not pregnant. There was no specified number of rebreeding attempts per cow before deciding to cull for infertility. The decision to cull for infertility was determined by the farm manager at Mapanga or technicians and lecturers at Bunda based on their experience and track record of the cows. Pregnancy diagnosis was done using both non return to oestrus and rectal palpation. Rectal palpation was done 3 months after the date of service.

Cows in smallholder farms were served through artificial insemination (AI, 45%), bulls (32%) or a combination of the two (23%) depending on availability. The AI was mostly (96%) done by farmer AI technicians and a few by the government AI technicians who were notified by either a phone call or phone message. Some farmers (24%) indicated that they walked to the technicians to notify them whenever AI service was required. Use of bulls was mainly (56%) due to inaccessibility of AI services. Some farmers also cited low AI pregnancy rate (30%) and lack of AI technicians as a reason for choosing to use bulls. Bulls used were selected based on accessibility (50%), type of breed (36%) and recommendation from extension workers (10%). Farmers reported that they had problems with use of bulls which included disease transmission, hiring and extra feed costs.

The average AI and bull hiring charges were MK2833±736[1] and MK2349±737. The charge for the bull was for a period of 3 days. There were significant differences ($p<0.0001$) in the bull hire charges between bulking groups. The highest average charge was in Machite at MK2828±797 followed by Chitsanzo, Lumbadzi and Dzaoneweka at MK2454±150, MK2000±408, and MK1250±645, respectively. About 30% of the farmers had access to pregnancy diagnosis services through rectal palpation which were done by the farmer AI technicians

[1] About MK421 was equivalent to one British Pound at the time of the study

or government veterinary officers. The majority of the farmers depended on non-return to oestrus for pregnancy diagnosis.

3.3.7 Recording

UK: Milk yields of individual cows in the Langhill herd were recorded at each milking and individual cow milk samples taken weekly for analysis of fat, protein and somatic cell contents. Live weights were measured after each milking. Body condition scoring was carried out weekly using the tail head system method (Mulvaney, 1977) on a scale of 1 to 5. Individual time budgets (standing, lying time and number of steps taken) were monitored in cows under BP and HG feeding systems using accelerometers (IceQubes®, Icerobotics Ltd, UK).

The individual feed and water feed intake was recorded on 3 days out of six using Hoko gates (Insentec BV, Marknesse, The Netherlands). Samples of complete diet fed and refusals were taken daily for determination of oven dry matter. Samples of complete diets and individual feeds were taken weekly and bulked into monthly samples for determination of chemical compositions. All feed samples were analysed at SRUC Analytical Services, Edinburgh. Digestibility of dry matter (DM) of the feeds was determined by the in vitro technique of Alexander (1969). The grass silage was analysed by near infrared reflectance spectroscopy (NIRS) to estimate metabolisable energy (ME) content (Barber et al., 1989). The ME content of the concentrate feeds was determined by the equation of Thomas et al. (1988):

ME (MJ/kg DM) = (0.14 NCGD) + (0.25 AHEE)

where

NCGD = neutral cellulose gaminase digestibility

AHEE = acid hydrolysis ether extract (g kg/DM) (MAFF,1993).

Grass heights were recorded twice weekly, when the cattle were grazing, using a mechanical rising plate meter (DairyCo, 2009). Health records were kept throughout the experiment and locomotion scores were recorded weekly, using a 1 to 5 scale (Manson & Leaver, 1988). Blood samples were taken from all cows every 6 months for analysis of genetic parameters of individual animals.

Stocking rates for grazing periods were estimated from the number of cow grazing days in proportion to the energy requirements of the two genetic lines (based on maintenance and milk yield). Stocking rates for housed periods were based on individual cow feed intakes related to crop yields with a 15% deduction for losses in storage and feeding.

All data collected at the farm were recorded on computers and transferred to the Langhill database. The data are available to staff and students for analysis and monitoring productivity at the farm. They provide information for making adjustments and other decisions on dairy production.

Malawi: Record keeping was routinely undertaken at Bunda and Mapanga Dairy Farms with all records kept in books and files. Records at Bunda were further transferred to computers. Routinely recorded data at Mapanga Farm included service and calving dates, sire, daily milk yield, births, disease treatment, culling and reasons for culling. Bunda Farm stored similar data as well weekly weights and body condition scores. It was noted that Mapanga Farm had a weigh bridge but weighing of animals was not a routine activity on the farm. Neither was body condition scoring systematically done, instead whenever need arose the animals were assessed visually on whether they were in good condition or not.

In smallholder farms recording was not a consistent routine practice although most farmers (76%) indicated that they kept records. The animals were identified by name (59%), ear tags (12%) or both names and ear tags (29%). Where records were kept they were mostly on milk sales, breeding and disease treatments (Table 3.8). On breeding, the records on AI varied but included insemination dates (46%), inseminator (42%), semen straw or bull ID (39%), source of semen (35%). For natural mating records were on bull ID (27%) and mating date (34%).

Table 3.8: The type of records kept in smallholder dairy farms

Record type	**n***	**Frequency (%)**
Milk sales	33	23
Disease treatment & drugs	39	27
Feeds	6	6
Breeding	35	24
Body condition score	1	1
Vaccination	11	8
Milk yield	10	7
Animal sales	3	2
Births	5	3
Total	146	100

*n=multiple response

A small proportion of farmers kept records on calving, insemination and dry off dates while others relied on their memory. When data on the most recent lactation were assessed, only a few could be used for analysis. When record books were checked, it was observed that the recording was neither systematic nor routine. It was as and when the farmer deemed it necessarily to note down a particular transaction or activity.

3.4 DISCUSSION

The production systems studied had both some common features and differences in the management of the farms. Similarities existed on breeds kept, some aspects of feeding, housing, management protocol, breeding and recording systems. Holstein Friesians were the breeds in the Langhill, Bunda and Mapanga herds as well as a relatively large proportion of the smallholder farms. There were also a few Jerseys at Bunda and some smallholder farms. However the genetic levels of breeds in Malawi were not known as they were not monitored. Also the adaptability of the breeds to the production environment in Malawi has not been studied extensively although exotic breeds have been in the country since the 1950s (Chagunda et al., 2004). Johnson et al. (1991) reported that high temperatures along with high relative humidity in the tropics cause stress in temperate breeds and negatively impact milk production. Some studies on the performance of Holstein Friesians in the tropics reported milk production levels that overlapped with production levels in the temperate regions (Makuza & McDaniel, 1996; Wollny et al., 1998; Ageeb & Hayes, 2000) while other studies reported lower production (Chagunda et al., 2004; Ahmed et al., 2007). The differences in the productivity were attributed to differences in the local production environment which included both climate and management.

Despite concerns of heat stress, production of exotic breeds continues in the tropics. This could be attributed to productivity of exotic breeds in the tropics being generally higher than that of most indigenous tropical breeds. Hence dairy development programs tend to favour the high producing exotic breeds. For instance the milk yield of the Zebu, is about 1 to 2 litres per day (Ranjhan, 1999; Nandolo, 2013) while Holstein Friesians breeds give an average of about 12 litres per day (Kawonga et al., 2012) under smallholder farming. However, it is not clear if the milk yield from the exotic breeds such as Holstein Friesians that are big and more labour demanding is able to offset the costs associated with other adaptability challenges in health, fertility, feeding and nutritional requirements. King et al. (2006) reported increased production costs for both low and high producing Holstein Friesians in the tropics due to high direct costs and inability to produce replacement heifers, respectively.

The adaptability of Holsteins Friesians and management abilities of resource constrained smallholder farmers in Malawi has not been evaluated. However, studies in similar farms in Uganda and Kenya showed presence of heat stress which varied with management system and location. Nassuna-Musoke et al. (2007) reported that cows managed under zero grazing were less heat stressed than cows that were grazed due to exposure to less solar radiation. King et al. (2006) reported a relatively higher stress in cows raised along the sea coast than the highlands in Kenya. This was attributed to the coastal temperatures that were constantly high both during the day and night while the nights in the highlands were cooler than the day. In a large scale study conducted in Malawi, the possibility of stress was also reported during the hot season. However, this did not have a significant effect on milk yield (Chagunda et al., 2004). Most smallholder farms in the current study used the zero grazing feeding system where cows were under the shade most of the times. There was a wide variability in the productivity of the smallholder farm herds as reported in chapter 4 which may depict differences in management and stress levels and needs further investigation. Further, King et al. (2006) reported that smallholder dairy production using high producing temperate breeds was profitable in the short term due to high milk yields but was not sustainable as the cows were stressed from heat loads and energy deficits culminating from climate and poor feeding systems, respectively. The stress results in reduced fertility, health and longevity of the cows. Instead King et al. (2006) recommend exploitation of indigenous breeds and their crosses with small sized exotic breeds. It is therefore important that the productivity of Holstein Friesians under smallholder farms in Malawi be further evaluated for decisions to develop sustainable dairy production systems.

3.4.1 Feeding Systems

Feeding management was similar in all the farms under study in that they used forages and concentrates. However, the rations and target feed intake and quality were different between farms. The Langhill and Bunda herd management had target milk yields and fed the animals according to their requirements for maintenance and milk production. The milk yields from the Langhill herds were close to the targets set from the feeding systems (March & Roberts, 2013) showing that the ration formulation suited the target yields. The milk yields at Bunda Farm were much lower than the target (Chaima-Banda, 2013) and this was attributed to the dairy herd being new coupled with lack of previous productivity records including the accurate genotype of the animals. This may also depict further need to evaluate breed productivity in relation to feeding systems.

This approach was not apparent in Mapanga and smallholder farm herds although the Mapanga Farm had a specific milk yield targeted. There was no clear basis for feeding the reported amounts of concentrates at both Mapanga and the smallholder farms and neither was feed intake monitored. Moran (2012) reported that sustainable dairy production requires good farm management that entails supplying sufficient inputs for the desired level of outputs. Good management includes setting achievable output targets and determining necessary requirements in terms of health, milk production, fertility and respective nutrients supplied in the diet to achieve the targets. The dairy production management in Mapanga and smallholder farms were seemingly left to chance and would unlikely be sustainable. Further, the amounts of concentrates given to cows at Mapanga were much higher than the recommendation in the tropics of 1kg concentrate for every 2-3 litres of milk produced (Ranjhan, 1999; Moran, 2012). Ranjhan (1999) reported that a 450 kg cow in the tropics that is fed crop residues would require 1.5 kg of by-product concentrate per day for maintenance and an additional 1kg for every 3 litres (or 2 litres according to Moran (2012) of milk produced.

The average weight of the cows at Mapanga was 451 kg. This implies that cows producing 8, 10 and 15 litres of milk per day were fed 5, 10 and 18 kg concentrates, respectively when they needed about, 4, 5 and 6 kg of concentrates, respectively. This indicates that there was overfeeding which unnecessarily increased feeding costs. Moran (2012) argued that the recommended concentrate milk yield ratio is a safety measure in the absence of knowledge on the nutritive value of feeds, otherwise knowledge of feeding value and associated costs would be more appropriate. This is because the amounts used would be more objective and most likely reduce feed costs where high quality forages are available. It is therefore important that information on the nutritional value of common forages in Malawi may be available to farmers to enable appropriate feeding recommendations and practices.

The amounts of concentrates fed to cows in smallholder farms varied widely meaning that some farms provided very low amounts while others provided relatively more. Njarui et al. (2011) reported feeding of consistently low amounts of concentrates of about 2kg per day throughout the lactation period in some smallholder dairy farms in Kenya. The practice could be due to lack of understanding of dairy cow feed requirements further constrained by the inconsistent availability and cost of the feed ingredients (King et al., 2006). Farmers feeding constantly low amounts of concentrates throughout the lactation period may not fully exploit the production potential of the cows. Kaitho et al. (2001) demonstrated that dairy cows yielded more milk when fed 8 kg of the concentrates per day only for the first 12 weeks of lactation as opposed to constant feeding of 2 kg per day throughout the lactation. The study demonstrated that feeding of concentrates could be stopped after the first 12 weeks without an adverse effect on milk yield. Further training of farmers, awareness campaigns coupled with monitoring and evaluation of cow productivity are required in order to improve dairy production. The monitoring and evaluation ought to provide feedback to the farmers relating the management practices to profitability of the dairy enterprise.

Rationalising the type of concentrate to use depending on affordability at a time shows the need to further work with farmers to develop medium to long term budgets for feeding animals. While farmers seemed to be aware of the importance of feeding dairy mash, apparently their perception was that maize bran was a direct alternative to dairy mash. It is important to demonstrate the differences in cow productivity attributed to feeding dairy mash as opposed to maize bran as well as demonstrate the importance of budgeting and consistent feeding of adequate amounts in relation to productivity (milk yield and fertility) and subsequent profitability. The practice of feeding maize bran also occurred at Bunda Farm, although only on rare occasions when dairy mash was not available. This may also be an indication of lack of appropriate planning for feeding dairy breeds. The farm similarly needs to revisit the feeding plans and budget such that the nutritional requirements of the cows are met throughout the lactation period.

Use of groundnut haulms served to supplement protein in the diet of the cows although the protein levels are lower than other legumes promoted for dairy production in Malawi such as Lucerne (*Medicago sativa*) and centrosema (*Centrosema pubescens*). Chingala et al. (2013) reported crude protein levels of 13, 21 and 25% in groundnut haulms, Lucerne and centrosema hay, respectively. These results show that there is further need to improve the type of feeds for dairy cows in smallholder farms.

The predominance of the cut and carry feeding system in smallholder farms was consistent with findings from other studies (Chindime, 2008; Kawonga et al., 2012). The system is recommended for smallholder dairy production as it offsets the risk of tick infestation and subsequent tick-borne disease infection. Tick-borne diseases such as East Coast Fever (ECF) are a challenge in Malawi (Huttner et al., 2001) and temperate breeds bred under tick-free conditions are highly susceptible to the disease (Gachohi et al., 2012). Use of free grazing at a few smallholder farms including Mapanga and Bunda Farms requires appropriate control of ticks. Cow mortalities due to ECF have been reported at Bunda Farm and this may imply inadequate tick control measures. Gachochi et al. (2012) reported the need for intensive acaricide application to disrupt *Theleria parva* transmission.

Water intake was *ad libitum* in the Langhill herd and Bunda Farm, but not at Mapanga and smallholder farms. It was not possible to quantify water intake at

Mapanga Farm while in smallholder farms the results showed that on average, each animal received about 39 litres of water per day. Even if the amount was to be adjusted for the ratio of adult animals to calves, the amount was below the recommendation for dairy animals. Moran (2005) reported a daily water requirement of 60-70 litres for maintenance and additional 4-5 litres for every litre of milk produced in dairy cows in the tropics. The requirement is even higher in the dry season reaching as high as 150 to 200 litres/day depending on milk yield. The amount of water given in the smallholder farms is far lower than the reported water intakes in the temperate regions where temperatures are much lower. Ward & McKague (2007) reported a requirement of about 68-83 litres of water for cows producing about 14 litres of milk per day in Canada. Cardot et al. (2008) reported daily free water intake of about 84 litres in France where ambient temperatures and milk yield ranged from -7 to 16^{o}C and 7 – 46 litres per day, respectively. About 75% of the water intake was during the day with more than 25% taken within 2 hours after each milking.

The results may imply that the importance of adequate water supply to the dairy animals is not understood. However, this has an implication on profitability of the dairy farms as water intake affects health and performance (Cardot et al., 2008). Studies have shown that milk yield and feed intake is reduced when water requirement is not met (Burgos et al., 2001; West, 2003). The requirement is even greater under heat stress conditions which are probable during the hot seasons in Malawi. Hence the farmers require more training and awareness on the importance of the quantity of water given to dairy animals.

3.4.2 Housing and health management

Housing and health management are important aspects of animal welfare. Fraser et al. (2013) reported that the physical environment for livestock should suit the species as well as the breed such that the risk of injury and disease transmission is minimised. The housing in the farms studied fell within the different type of cattle housing suitable in the temperate region and tropics, respectively. Housing for the Langhill herd was designed to allow free access to feeding, drinking and loafing areas as well as protection from adverse weather and consistent removal of slurry. The pens in all farms in Malawi were sheds with open sides allowing for adequate ventilation and lighting. The floors were at a slope and of concrete in line with recommendations for dairy cattle husbandry (Moran, 2012) except in some smallholder farms where drainage and roofing were poor. Some studies have shown that housing systems with concrete floors were more associated with hoof disorders than rubber floors (Fjeldaas et al., 2011). Cook & Nordlund (2009) also reported that concrete floors and zero grazing were among the major risk factors for lameness, a disease which is one of the welfare problems for dairy cows. However, hoof disorders have not been reported as a challenge in the farms under study in Malawi. Further, lameness was not monitored on the farms and hoof trimming was not a routine practice. Therefore presence of the problem may not be completely ruled out coupled with the fact that lameness detection by farmers was not obvious (Whay et al., 2003). It may therefore be appropriate that lameness monitoring and routine hoof trimming be put in place to ensure that such disorders, if any, are treated accordingly.

The housing in all the farms apart from some smallholder farms were designed to allow cow comfort as well as health through availability of adequate space, ventilation and hygienic environment. Facilities that enabled appropriate husbandry practices were available such as crushes, sick bays, calving pens, calf pens, milking parlours, feed stores and slurry drainage and storage systems. Cleaning frequency and slurry management were different between farms. Slurry removal was continuous in the Langhill herd enabling a clean environment throughout production with slurry stored in closed tanks. Mapanga and Bunda Farms cleaned the pens once per day with manure composted in heaps. The frequency of cleaning at Bunda and Mapanga was adequate as pens were kept dry with not much dung accumulation. However, the mode of manure storage might need modification when their use and environmental concerns are taken into account. Nutrient losses have been reported through volatilization and leaching (Lekasi et al., 2003; Jackson & Mtengeti 2005) and gaseous emissions from manure into the atmosphere (Oenema et al., 2007) are detrimental to the environment.

Differences in housing structures as well as poor drainage and roofing among smallholder farms may indicate selective adoption of technologies or lack of understanding of the importance of appropriate dairy husbandry. It is important that extension services continue to follow up with emphasis on animal welfare and profitability.

3.4.3 Management protocol and recording

Some aspects of management protocol and data recorded were similar but some procedures and recording in Malawi farms were less detailed and need further improvement. For instance heat dates prior to service, feed quality, feed and water intake were not recorded. The systems also had challenges with availability and efficiency of AI services due to resource constraints which was not the case with production in the Langhill herd.

Some of the records available at Bunda Farm were used to evaluate milk production in response to various feeds available at the farm. However, there is potential for further utilisation of these records in health, reproductive and housing management for further improvement of dairy production within the farm and other farms. Keeping of records in smallholder farms was more to do with tracking income and payments rather than monitoring productivity of the farm. The use of the records kept at Mapanga Farm was not apparent although they were well kept in books and files. For instance although the farm ideally followed a voluntary waiting period of 60 days from calving before inseminating cows, data showed that some cows were inseminated as early as 16 days from calving. Such incidences may depict lack of appropriate monitoring techniques and use of records. The data at Mapanga were accessible for research but require an improvement in the storage systems for ease of access and utilisation.

In contrast, the records from the Langhill herd are well organised and in a database that was readily accessible to the farm and research staff as well as students. Data accumulated for a period of over 15 years were available and enabled evaluation of various aspects of the farm and numerous publications have been produced from the data thereby providing feedback to both the research farm and other farms for improved dairy production.

While the information from farms studied in Malawi may not necessarily be suitable for other farms or publications, appropriate record keeping and utilisation would contribute to appropriate decision making and adjustments within farms for increased productivity and profitability. It would therefore be worthwhile to strengthen appropriate record keeping and demonstrate their use on farm and the link to profitability which is of prime importance to the farms.

3.5 CONCLUSION

The production systems under study showed both differences and similarities in the management systems. The production systems in Malawi were generally faced with challenges that limited implementation of some appropriate husbandry practices while the Langhill herd had more advanced technologies with fewer challenges. There were similar breeds and similarities in some aspects of feeding and management protocol in all the production systems. Production systems in Malawi need further evaluation on performance and profitability of exotic breeds in the long term and develop appropriate strategies for sustainable dairy production. The Malawi feeding systems also need further improvement to meet the nutritional requirements of dairy animals. Housing, health and records management were mostly appropriate in all production systems with some aspects of housing material, waste and records management in Malawi requiring further assessment and improvement in relation to animal welfare and utilisation.

CHAPTER 4: EFFECT OF FEEDING SYSTEMS ON COW FERTILITY AND ACTIVITY

4.1 INTRODUCTION

Dairy production is important in both developing and developed countries and production has rapidly increased over the past decade (FAO, 2013). While some developing countries such as India and Brazil currently produce substantial amounts of milk and appear among the top ten world high milk producing countries, the production in many developing countries within Sub-Saharan Africa has remained low. Total milk production in Malawi was 0.05 million tonnes in 2011 while the highest cow milk producing country in Sub-Saharan Africa was Kenya with about 4 million tonnes. Kenya was thirty second in the world listing of high cow milk producing countries.

When the production level for Malawi is considered from within country, there has been a significant increase over the past 10 years (DAHLD, 2012). This is similar to many developing countries as Gerosa & Skoet (2012) reported a greater percentage increase in milk production in some developing countries than in developed countries. The higher rate of increase emanated from a relatively low base compared to developed countries and was attributed to both demand and technological advances that led to the emergence of large-scale dairy production. At the same time smallholder farmers also played an important role as they dominate the dairy industry in the developing countries (Chagunda et al., 2006; Morgan, 2010). Smallholder dairying is likely to continue despite inefficiencies associated with the production system. This is because dairying contributes to improved livelihoods in terms of nutrition, income generation and social capital. In some countries like Malawi and Kenya there are deliberate policies to promote smallholder dairy production. Hence there is need to help improve production factors that contribute to the inefficiencies associated with smallholder production systems. The factors contributing to inefficient production are linked to limited resource (capital, feed and breeding stock) availability and access to extension, health and other support services (Goyder & Mang'anya, 2009; Morgan, 2010). The limited access to resources is portrayed through poor animal nutrition and health which in turn translate to low milk yield and fertility.

Low fertility results in reduced reproductive efficiency and the subsequent expansion and sustainability of dairy farming. It is therefore important that the problem is addressed. However, the problem of low fertility is complex and has been a point of focus in various studies and countries for the past 3 decades. The current study sought to contribute towards developing solutions to the problem by further exploiting associations between fertility and other productivity traits such as milk yield, energy balance and activity. Cow activity has long been used to determine oestrus in cycling cows (Firk et al., 2002; Lovendahl & Chagunda, 2010; Palmer et al., 2010) and also used to study animal behaviour in relation to health and welfare status (O'Callaghan et al., 2003; Barrientos et al., 2011; Rushen & de Paselle 2012).

This study was carried out to characterize factors that affect cow fertility and other productivity traits in Malawi while using data from the United Kingdom (UK) as a benchmark for developing improved management systems. The UK is among the world top ten (ninth) cow milk producing countries with 14.2 million tonnes in 2011 (FAO, 2013). This approach was used so that the UK data provided a tangible benchmark through which production systems could set goals to improve aspects to achieve improved productivity levels.

4.2 MATERIALS AND METHODS

Data for the benchmark study from the UK were obtained from a database available at Scotland's Rural College (SRUC) which was compiled from the Langhill pedigree herd at the SRUC Dairy Research Centre in Dumfries. The results from analysis of these data were used to guide data collection in Malawi where the effects of feeding systems and management on fertility were investigated through a feeding experiment and monitoring of smallholder farms and a commercial dairy unit. The feeding experiment was conducted at Bunda College while farm monitoring was carried out in purposely selected smallholder farms in Lilongwe Agricultural Development Division and at Mapanga Dairy Farm in Zomba, Malawi.

4.2.1 Characterization of factors affecting fertility in the UK Langhill herd

The Langhill herd consisted of Holstein Friesian cows from two genetic lines (Select and Control) selected on the basis of genetic merit for kilograms milk fat plus protein. This genetic selection project was started in the early 1970s. The Select (S) group cows were sired by bulls with high predicted transmitting abilities (PTA) for fat plus protein yield, whereas the Control (C) cows were sired by bulls of UK average merit for fat plus protein (Pryce et al., 1999). The cows were moved from the Langhill Farm in Edinburgh to the SRUC Dairy Research Centre in 2002 and managed as one group, for six months. After six months the cattle were allocated to pairs on the basis of genetic line, lactation number, calving date, milk yield, live weight and previous experimental treatment. Animals were then allocated within pairs to two different management systems a low forage system (LF) and a high forage system (HF). There were four experimental groups comprising two feeding systems (LF and HF) and within each feeding system two genetic lines (S and C). The four experimental groups constituted the four production systems herein referred to as LFS, LFC, HFS and HFC, respectively. The cattle were managed on the two systems from July 2003 and the experimental monitoring started in April 2004 after nine months adaptation to the systems.

Later, in 2011, the cows on the high forage system were all transferred to a system based on all feed grown on the farm (HG) and those on the low forage system were transferred to a feeding system based on by-products (BP). This new feeding system formed production systems known as HGS, HGC, BPS and BPC, respectively. Each production system was comprised of approximately 100 cows in their first 3 lactations. At the end of their third lactation the cows were replaced by heifers due to calve within 2 months. If there were no suitable replacements then cows remained on the system for an additional lactation (Roberts & March, 2013).

4.2.1.1 Data collection

Milk yields, body condition score on a scale of 1 to 5, cow health, fertility, feed intake and composition were collected as described in chapter 3. Table 4.1 shows the typical chemical composition of the feeds. Fertility records included calving ease and dates of calving, first heat, service date, pregnancy diagnosis and next calving.

Table 4.1: Feed chemical composition of rations and target production for the Langhill herd

Variable	Type of ration (Mean ±SD)			
	High forage	Low forage	Home grown	By product
Crude protein (g/kg)	180±5	185±5	180±7	185±7
Metabolisable energy (MJ/ kg DM)	11.5±0.2	12.3±0.2	11.5±0.3	12.3±0.3
Dry matter (%)	30	45	38.4	50
Intake (kg DM/cow/day	21.3	23.4	15.8	22.1
Milk production (litres/cow/year)	7500	13000	7000	11000

4.2.1.2 Data Management

Data were retrieved from the Langhill database using the SQL Server Management Studio 2008 and exported to Microsoft Excel 2007 where the data were cleaned. Cleaning included removal of duplicates and deletion of entries that had missing variables and these accounted for about 2% of the data. The duplicates were not existent in the database but came about during the process of retrieving data which involved connecting several tables from the database. Cleaned data were then exported to SAS 9.3 for analysis.

Three sets of records were retrieved separately. The first set (dataset 1) had a total of 1179 records retrieved from 383 cows between their first and fourth lactation that calved between September 2003 and December 2010. Traits included animal identification, date of birth, genetic group, feeding system, lactation number, calving date, weight and body condition score (BCS); first and last service dates, total number of services, last service weight, BCS and milk yield, and pregnancy diagnosis results. Body energy content (BEC), changes in BEC and BCS, milk yield acceleration, calving interval number of days to first high luteal activity, recorded heat, service and successful service were calculated. BEC at calving and service were calculated using the formulae summarized below (NRC 2001; Banos et al., 2006).

$$\text{BEC (MJ)} = [(9.4 \times \text{body lipid weight}) + (5.7 \times \text{body protein weight})] \times 4.1868 \quad (4.1)$$

Where:

Body lipid weight (kg) = (0.037683 x BCS) x (empty body weight)

Body protein weight (kg) = [0.200886 – (0.0066762 x BCS)] x empty body weight

BCS were expressed on a scale of 1 to 9 (BCS9). The BCS in the database were on the scale of 1 to 5 (BCS5) and were converted to BCS9 using the formula:

BCS9 = (BCS5 -1) x 2+1

Empty body weight (kg) = (live weight (kg) × 0.96) × 0.851.

BEC is one of the body energy measures used in other literature (Banos et al., 2006; Coffey & Pollot, 2008). The trait indicates the absolute level of energy in the body per day regardless of previous day's energy use and intake (Banos et al., 2006). Changes in BEC from calving to nadir BEC and service were also calculated. Nadir BEC was defined as the lowest BEC in the lactation.

Change in BEC from calving to successful service

$$\Delta BEC(\%) = \frac{BECs - BECc}{BECc} x100 \quad (4.2)$$

Where ∆BEC = percentage change in body energy content

BECs = body BEC at service

BECc = body BEC at calving

Change in BEC from calving to BEC nadir

$$\Delta BEC(\%) = \frac{BECn - BECc}{BECc} x100 \quad (4.3)$$

Where ∆BEC = percentage change in body energy content

BECn = lowest BEC in the lactation

BECc = BEC at calving

The BCS change was taken into account as it has been reported to affect fertility (Butler, 2003) and was calculated as

$$\Delta BCS = BCSs - BCSc \quad (4.4)$$

Where ∆BCS = change in BCS

BCSs = BCS at service

BCSc = BCS at calving

Milk yield acceleration (MYA) is a measure of the increase rate of milk yield over time and more accurately indicate lactation biological changes (Domecq et al., 1996) and was calculates as

$$MYA = \frac{MY_{d2} - MY_{d1}}{d_2 - d_1} \quad (4.5)$$

Where MYA = milk yield acceleration (rate of change in milk yield in litres per day)

MY_{d1} = first recorded milk yield in the first week of lactation

MY_{d2} = first highest milk yield recorded

d_2=interval from calving to first highest milk yield (days)

d_1= interval from calving to first recorded milk yield (days)

Days to first high luteal activity (DFHLA): the interval in days from the calving date to the date when plasma progesterone concentrations first exceeded 3ng/ml (Bulman & Lamming, 1978).

Days to first recorded heat (DFH): the interval in days from the calving date to the first heat date recorded in the database.

Days to first service (DFS): the interval in days from the calving date to the first service date recorded in the database.

Days to successful service (DSS): the interval from the calving date to a service date recorded in the database with a subsequent calving date and gestation length of 282±14 days (Pryce et al., 2002)

Calving interval: the number of days from calving to the next calving date with a voluntary waiting period of 42 days and gestation length of 282±14 days from the recorded date of service.

The second dataset (dataset 2) comprised all the traits in the first set and lactation weekly body weights, BCS and milk yield. A total of 47405 records from 367 cows were retrieved. Trends in milk production and changes in body energy content throughout the lactation and production systems were studied using these data.

The third dataset (dataset 3) was from the feeding systems that started in 2011 with the Langhill herd and comprised a total of 7430 records from 280 cows with their lactation between November 2011 and December 2012 were retrieved using the Microsoft SQL Server Management Studio 2008. Out of the 280 cows, 79, 76, 75 and 73 cows were control cows on by product feed (BPC), control cows on home grown feeds (HGC), select cows on by-product feeds (BPS) and select cows on home grown feeds (HGS), respectively.

Data retrieved included weekly milk yield, weights and body condition score. Body energy content was calculated using weights and body condition score as described above. Data on activity of the cows between December 2012 and February 2013 were also retrieved. This was the time when all the animals were housed for winter. The activity data included weekly averages of duration of lying and standing, motion index, as well as number of steps and lying bouts. The activity dataset had a total of 8602 records from 119 cows while the eating time data set had 8079 records from 115 cows. Eating time data included daily summaries of total time spent eating from the Hoko bins. Cows included were only those having at least 30 days from which daily activity and eating time were recorded.

4.2.2 Effect of feeding on cow productivity and activity at Bunda Farm

An experiment was carried out at Bunda College Students Farm in Lilongwe between January and June 2012. The aim of the experiment was to generate information that demonstrates the relationship between the level of feeding, milk yield and the activity of dairy animals. At the same time the study was designed to give an understanding of how activity meters work under tropical conditions and highlight issues that need to be taken into account to improve dairy cow production.

4.2.2.1 Experimental Animals

The experiment involved two feeding levels of the dairy herd at Bunda College Animal Science Department Student Farm. Two feeding levels were targeted due to the small numbers of cows available at Bunda College. Nine Holstein-Friesian and nineteen Holstein-Friesian x Malawi Zebu cows were allocated to either maize bran or dairy mash as a concentrate. The allocation of cows to each feeding level was systematic where animals were paired according to genotype, parity, days in milk, body condition score, weight, calving ease, fertility and health history. This was done in order to minimise bias in the allocation of animals to the treatments. In addition to tags, animals belonging to each feeding level were fitted with coloured collars to easily distinguish animals between treatments.

4.2.2.2 Feeds and Feeding

One group of animals was fed forages and a concentrate comprising maize bran and salt. The forages included Rhodes grass (*Chloris gayana*), Napier grass (*Pennisetum purpureum*); groundnut (*Arachis hypogaea*) haulms and Centrosema (*Centrosema pubescens*) in the form of hay. The other group was fed the same forages and dairy mash as a concentrate. The dairy mash comprised maize, maize bran, groundnut cake, salt, mineral and vitamin premix, lime and monocalcium phosphate. The forages and water were provided ad lib while the concentrate was given twice a day at 7kg/cow/day, in the morning and afternoon.

The animals were housed in pens throughout the experimental period and individually fed using cut and carry method. Feed consumption was recorded through weighing the amount of feed given and the amount left at each feeding. Fresh forages were provided every morning.

Feed samples of grass, legumes, and concentrates were collected from three different batches of feeds and analysed for dry matter, crude protein, ash and gross energy content. Duplicate samples from each batch were prepared and analysed following standard procedures (AOAC, 2002). Samples (5g) were oven dried at 105 °C overnight for DM determination. Crude protein (N × 6.25) was determined using the Kjeldahl method while ash content was estimated by charring a pre-dried sample in a crucible at 600 °C until white ash was formed. Gross energy was measured using a bomb calorimeter (WZR-1T-B).

4.2.2.3 Animal activity monitoring

Animal activity was monitored through use of accelerometers (IceQube Sensors®, Icerobotics Ltd, UK) that were tagged on each of the twenty eight animals available for the experiment. Monitoring of animal activity was undertaken to complement data on post calving return to oestrus obtained through physical heat observation. Activity monitoring is widely used in heat detection (Firk et al., 2002; Lovendahl & Chagunda, 2010; Palmer et al., 2010; Yoshioka et al., 2010). Detection of oestrus using accelerometers is based on increased level of activity during oestrus which can be measured using the accelerometers (Firk et al., 2002).

Each IceQube had a unique identification number which was linked to the cow identification number and was attached on either the left or right rear leg above the fetlock joint. Cows were tagged on the day they were introduced in the experimental treatments and the IceQubes remained attached until the day of downloading the data. The data were downloaded onto a computer using an IceReader® desktop download unit and this was done every 21 to 28 days. The IceQubes were reattached on the cows about 6 hours from the time they were detached. There were cases when the IceQubes slipped off the legs of the cows and these were reattached as soon as they were noticed. Before reattachment, the legs were checked for lesions or any sign of injury. No such cases were recorded throughout the experiment.

The downloaded data comprised 15-minute block summaries of the motion index, number of steps, lying bouts, standing and lying durations making a total of 96 entries for each variable per day. The 15 minutes summaries were later aggregated into daily summations for each of the variables. Hence the IceQube determined how long a cow was lying or standing, the number of steps and lying bouts taken and the overall activity per day. Overall activity was measured by the motion index which was determined by measurement of acceleration against gravity on each of the three body axes (de Mol, 2013). A high motion index meant a lot of movement and this is highly correlated with the number of steps that an animal takes (Rushen & de Paselle, 2012).

Malfunctioning IceQubes were identified after downloading data and indicators of malfunction included blank records, total daily motion index and number of steps of zero and less than 96 entries for any variable per day. Days with such records for the affected animals were excluded from the analysis. When the total number of animals per day for each treatment was less than two then the treatment was excluded from the analysis for that day. The final data set that was analysed comprised 1241 entries from 27 cows with each cow having activity data for an average of 48±18 days.

4.2.2.4 Data Collection

Data on milk yield and animal activity were collected from December 2011 to June 2012. Daily milk yield data were compiled from morning and afternoon milking records for each animal. Animal activity data were summarised into daily total motion index, number of steps and lying bouts, standing and lying durations. Inconsistency in the recording of the accelerometers was observed such that there were days when no data were recorded at all. Such days were excluded from the analysis and only those days when there were at least three cows from each treatment having complete daily records were used. Because of this challenge, the accelerometers did not provide data for heat detection. However the data provided some insight in the relationship between feeding systems and daily animal activity.

4.2.3 Effects of management systems on cow fertility and activity

Twenty five smallholder farms with a total of 28 Holstein cows were sampled from Chitsanzo Milk Bulking Group (MBG) in Dedza District under Lilongwe Agricultural Development Division (LADD) using a purposive sampling method. The selection was preceded by a baseline survey that was undertaken in four MBGs, namely Lumbadzi, Machite, Dzaonewekha and Chitsanzo within LADD to find availability and suitability of dairy farms to be involved in the study. The purpose of this study was to determine the effect of dairy management practices on milk production and fertility. The baseline survey was carried out to determine background information on practices in dairy management in the study area. This information was used to select the MBG and the farms where the monitoring study would be carried out. Chitsanzo MBG was chosen based on availability of relatively higher numbers of farms that met the study selection criteria as well as ease of accessibility. The study selection criteria were cows that had calved no more than 90 days from the start of the study period and not confirmed pregnant.

4.2.3.1 Baseline survey

Individual household interviews were used to collect data using structured questionnaires that were administered to dairy farming households (Appendix 1). The questionnaires included questions on management practices in breeding, record keeping, feeding, housing, health and milk production. Access to inputs and other services such as extension and health was also investigated along with associated challenges. The data were collected to identify the key practices that influence cow productivity. Access to services and challenges faced were included as they affect the extent to which farmers follow the recommended husbandry practices.

Data on breeding included the source of initial stock, mating system, births and the most recent insemination and calving dates. Calving and insemination dates were used to estimate fertility traits. The fertility traits were calving interval and number of days from calving to insemination. Record keeping data included the type of records and reasons for keeping them. Data on types and amounts of feeds, feeding frequency and availability were used to describe feeding management. Water sources and availability to the animals was also investigated. The quantity, type and appearance of feed and water available to the animals at the time of the interview were also recorded. Housing management was assessed through physical checking of the hygiene, structure and availability of all recommended components. Disease incidences and treatments were used to provide an overview of animal health management. Milk production at onset, peak and late lactation as well as fertility traits were related to the management practices to determine if there were any differences in productivity that could be attributed to management.

4.2.3.2 Farm Monitoring Study

The selection of farms involved in the monitoring study targeted farms with cows that had calved less than three months from the start of the study in May 2012. Twenty five smallholder farms were involved in the study with a total of 28 Holstein Friesian cows. The study started with 21 cows from 18 farms and 7 more cows were added as they calved. The farmers were briefed on the purpose of the study and how data collection would be done with clarifications provided where they were needed. Data collected included calving, heat and service dates; weights, body condition scores, milk yield, progesterone, fat and protein, animal feeding and housing management. The parity of the animals was included where data were available.

Milk fat, protein and progesterone content were analysed twice a week while body condition score, weight, health, feeding and housing management were assessed once a month. Milk yield records were obtained from the milk collection centre at the MBG. Milk fat and protein were determined using a milk analyser (Milk-Lab Compact®, Milk-Lab UK Ltd). Milk fat data were not used in the analysis as the figures were unrealistic (0.2 to 11.3%). The unrealistic figures were due to variations in the way farmers collected the test samples. It seems some farmers collected the milk sample from the surface while others collected the last few drops from milking buckets after standing the milk for some time. This might have contributed to the wide variation in the figures as fat accumulated at the top after milk is left standing for some time. Reported fat content in milk from Holstein x Zebu crosses is 2.29-3.09% (Froberg et al., 2007; Santos et al., 2012) while for Holsteins in Malawi it is 3.8% (Chingala et al., 2013).

Progesterone assays were done using the Ridgeway Science® UK milk progesterone kits where duplicate 10 µl milk samples and standards were mixed with a progesterone enzyme and left at ambient temperature for 1 to 1½ hours, washed in water then mixed with a substrate buffer and left for about 30 minutes. Colour development was either strong or weak depending on progesterone concentration in milk samples and standards. Standards had a concentration of 0, 1, 2, 5, 10, 20 and 50 ng/ml. The colour reactions of the samples and standards were strong for low progesterone concentration (0-2 ng/ml) meaning that an animal was on heat and not pregnant and weak for high progesterone concentration (10-50 ng/ml) meaning that the animal was in mid-oestrus or pregnant. The colour reaction for the 5 ng/ml standard was intermediate and was used to mark the day of first 'high' luteal activity. Hence the days to first high luteal activity were defined as the number of days from calving to the first time a milk sample from the cow showed an intermediate or weak colour reaction. Weight was estimated from heart girth measurements while body condition score was on a scale of 1 to 5 according to the tail head systems (Mulvaney, 1977).

Eleven of the 28 cows were tagged with accelerometers (IceQubes®, Icerobotics Ltd., UK) in order to monitor the activity of the animals as described in section 4.2.2.3 above. This was in order to complement data on post calving return to oestrus obtained through physical heat observation by farmers and bi-weekly milk progesterone measurements.

Farms were classified according to the three tier system described by Kawonga et al. (2012). All the 25 farms involved in the study were in tier 3. Tier 3 farmers are those with better animal welfare and milk hygiene. Fortnightly farm audits were carried out in order to describe farm management. A total of farm audits ranging from 5 - 8 were made on each farm between May and August 2012. Each farm was assessed and scored using a checklist (Appendix 2) adapted from Kawonga et al. (2012). The management aspects included were cow appearance, feeding level and housing. The characteristics scored under cow appearance were claw and coat cleanliness, alertness, presence or absence of lesions and swellings. Presence or absence of claw, eye and muzzle abnormalities were also included. Feeding level was scored using availability, quantity and quality of water, forages and concentrates. Forage chopping and dryness were also taken into account. The type of concentrate used was also recorded. Housing characteristics included availability of exercise area and beddings, floor dryness and cleanliness. To score the farms according to feeding level and pen hygiene, the coding in Appendix 2 was reorganized to form a progression scale as outlined below:

Feeding level

Water availability (WA): Absent=0; present=1

Water cleanliness (WC): dirty =0; clean=1

Forage availability FA): absent=0; present=1

Forage chopping size (FC): not chopped=1; too big=2; good size=3

Forage dryness (FD): too dry=1; too moist=2; good=3

Type of concentrate (TC): maize bran=1; dairy mash=2

Pen hygiene

Floor status (FS): wet & dirty=1; dry & dirty=2; wet & clean=3; dry & clean=4

The total scores for each farm from the eight farm audit visits made were compiled and as expressed as a percentage of the total possible score (TPS) that could been achieved by each farm in each category. The TPS for each farm depended on the total number of farm audits made and the scores ranged from 55 to 88 and 20 to 32 for feeding and pen hygiene, respectively. Hence the percentage scores for each category were calculated as follows:

Feeding level (%) = (WA + WC + FA +FC + FD + TC)/TPS x 100

Where WA= total score for water availability from all farm audits

WC= total score for water cleanliness from all farm audits

FA= total score for feed availability from all farm audits

FC= total score for feed chopping size from all farm audits

FD= total score for feed dryness from all farm audits

TC= total score for type of concentrate from all farm audits

TPS= total possible score from all visits

Pen hygiene (%) = (FS/TPS) x 100

Where FS= total score for floor status from 8 farm audits

TPS= total possible score from all visits

The percentage scores for feeding levels and pen hygiene were then described as low, intermediate and high if they were ≤49, 50-74, ≥75%, respectively. Table 4.2 gives a summary of the number of farms in the different management categories.

Table 4.2: Number of farms in each management aspect assessed at Chitsanzo Milk Bulking Group in Lilongwe, Agricultural Development Division

Management aspect	Description	Number of farms
Type of concentrate	Maize bran	7
	Dairy mash	21
Feeding levels	Low	4
	Intermediate	11
	High	13
Pen hygiene	Low	3
	Intermediate	14
	High	10

4.2.4 Effect of feeding levels on milk production and fertility on a large scale farm

Mapanga Dairy Farm is a constituent of Global Tea & Commodities Ltd which was formerly operated under Sable Farming. The farm was established in the early 1960s as part of Colonial Development Corporation and later managed under Malawi Young Pioneers (MYP) as a Government farm. After structural adjustment the farm was privatised under Sable Farming Company Ltd, a subsidiary of Global Tea & Commodities Ltd. As of September 2012, the dairy herd comprised 291 Holstein Friesian young stock and adult cattle of which 100 and 41 were milking and dry cows, respectively.

4.2.4.1 Data sources

Primary and secondary data were collected from the farm. Secondary data were obtained from record books available at the farm and included insemination and calving dates, type of insemination, calf births and milk production. Primary data were collected from animals that had just calved and were within their voluntary waiting period (VWP) of 60 days as per practice by the farm. Animals beyond the VWP were included if they were not confirmed pregnant. The animals were in three categories based on their milk yield – high (15 litres/day and above); medium (10 to14 litres/day) and low (less than 10 litres/day). The farm refers to the cows in these categories as super, A and B, respectively. In this thesis the cow groups are referred to as high, average and low producing cows, respectively. Data were collected from a total of 62 cows.

4.2.4.2 Feeding System

The feeding system for the animals was based on milk production. High producing cows were those producing at least 15 litres per day per cow but less than 6 months in lactation. These cows were fed 18 kg of concentrates per day. After some time, based on visually assessed body condition and production, a cow from this group was moved to either average or low producing group depending on milk production. Average producing cows produced 10 to 15 litres of milk per day and were supplemented with 10 kg of concentrates per day. When milk production and body condition declined the cows were moved to the low producing group. Low producing cows produced less than 10 litres of milk per day and were supplemented with 5 kg of concentrates per day per cow. The concentrates were fed to the cows twice per day immediately after milking. The milking times were from 3.30 to 6.00 a.m. and 2.00 to 5 p.m.

Other supplements such as maize silage and/or hay were provided in the pens. The cows grazed in paddocks between 8.00 a.m. and 1.00 p.m. The pastures were dominated by Kikuyu grass (*P. clandestinum*) and star grass (*Cynodon nlemfluensis*). There was also some Napier grass (*P. purpureum*) and Leucaena (*Leucaena leucocephala*) that were rarely used to feed the animals through a cut and carry system. From the grazing field, the cows were confined for one hour and given access to water in readiness for milking between 2.00 pm to 5.00 pm.

4.2.4.3 Data Collection

The data collection was done between 22nd October, 2012 and 7th February, 2013. Thirty nine of the cows were tagged using accelerometers (IceQubes®, Icerobotics Ltd, UK) which were used to monitor animal activity as described in section 4.2.2.3 above. However, data from 24 out of the 39 could be used for analysis as some accelerometers were lost in the grazing field while others fell off and herdsmen replaced them on the wrong animals. Out of the 24, data from 6 accelerometers were excluded as they were not recording data most of the time. The final dataset comprised 766 records from 18 cows and each cow had activity data for 43±15 days. The challenge with the accelerometers was that they did not fit firmly on the legs of some of the cows which were much thinner than the smallest size that the accelerometers could fit.

Accelerometers were used to complement data on post calving return to oestrus obtained through physical heat observation by herdsmen. However, with the inconsistent recording of the accelerometers coupled with the fact that most of the animals did not return to oestrus within the experimental period, it was not possible to associate activity to oestrous behaviour. Instead, the data were used to determine animal activity in relation to feeding systems and management routine.

Other data collected included:

- Animal ID
- Date of birth
- Lactation number
- Calving dates
- Calving interval preceding the calving that was monitored
- Weekly weights. The accuracy of the weigh bridge was checked on monthly basis against a known weight of a 50 kg bag of maize.
- Weekly BCS
- Daily milk yield
- Service dates
- Type of service (AI or Natural).
- Time and amount of concentrate (dairy mash) given and amounts left
- Ingredients used to make the dairy mash
- Samples of each batch of dairy mash were taken to Bunda College for proximate and energy content analysis.
- Types and samples of forages grazed as well as silage and hay were also taken to Bunda College for proximate and energy content analysis

Records available on the farm on any of the data listed above were collected and used to provide background information of the farm. The farm had no computer for record keeping and all records were in books and files and these were photocopied and data entered on Excel spreadsheets. It was noted that the farm had a weigh bridge but weighing of animals was not a routine activity on the farm. Neither was body condition scoring systematically done, instead whenever need arose the animals were assessed visually on whether they were in good condition or not. Routinely recorded data included service and calving dates, sire, daily milk yield, births, disease treatment, culling and reasons for culling.

4.2.5 Data analysis

Data were analysed using descriptive statistics, crosstabs, frequencies and mixed models using Statistical Analysis System (SAS 9.3). Least square means were generated and separated using probability difference. Graphs showing relationships between traits were generated using Microsoft Excel 2007. Mixed models were used on data with repeated measures to test the effect of parity, genotype and feeding system cow productivity traits that included milk yield, milk quality, body energy content, fertility and cow activity. The effect of BCS on fertility was also tested on log transformed days from calving to first recorded heat (DFH) and to successful service (DSS).

The fixed variables for the data from Mapanga Farm included the parity and the cow feeding groups of high, medium and low producers. To analyse fertility and milk yield traits from these data, the cows were regrouped based on whether they were continuously in the same feeding group or changed feeding group in early lactation (the first 70 days in milk).

All data on milk yield, fertility, BEC, motion index, number of steps, standing, lying and feeding durations were subjected to the generalised mixed linear model (GLIMMIX) procedure of SAS 9.3 where differences in the response variables were determined between the feeding systems, genotypes and other management practices. A log transformation was done to normalise BEC, DFH and DSS data. The normally distributed data on milk yield and transformed BEC, DFH, and DSS data were then analysed using generalised mixed linear models (GLMM) with a normal error distribution and a log link function, while the count data on activity data were analysed using GLMM with negative binomial error distribution and a logit link function. A negative binomial error distribution was opted for in the count data analysis as a Poisson error distribution resulted in over-dispersion.

The generalized linear mixed model was as follows:

$Y_{ij}=a+\Sigma b_i x_i + \lambda_i + \varepsilon_{ij}$

Where: Y_{ij}= trait outcome

a= intercept

b_i=*i*th fixed effect (i=1,2,3 ... parity, feeding system, genotype, housing hygiene)

x_i=value of *i*th fixed effect

λ_j =random effects of cow, week of lactation

ε_{ij} =Error

Kendall's tau correlation was used to determine the relationship between physical heat detection, activity monitoring and milk progesterone for data from Malawi.

4.2.6 Study limitations

Not all data on traits recorded in the UK Langill Herd could be obtained for the herds in Malawi. This was due to several limitations such as inadequate records due to only a few cows that calved and were milking or detected on heat and served during the study period. In other cases resources such as services, time and equipment were a limiting factor. The study was done when there was fuel shortage in Malawi which resulted in a smaller sample size of smallholder farms than planned for both the baseline and monitoring study. The farms involved were limited to areas that could easily be accessed. Even for the farms that could be accessed, the number of visits was still limited by fuel availability. In addition, the number of households interviewed during the baseline survey was further limited by accessibility to the farms and availability of the farmers for interviews. The only time available to conduct the baseline survey was in the rainy season (January 2012) when road conditions are poor and farmers tend to dedicate more time towards crop production.

Milk quality could only be measured for smallholder farms and at Bunda College Farm. Calving weights and body conditions scores (BCS) could not be captured for all farms as most cows calved before the commencement of the study. On milk yield, only nine cows were milking at Bunda and they were all of different parities and at different stages of lactation, hence the data were excluded. The smallholder farmers did not record milk yield unless they sold the milk at the MBG and the milk yield recorded excluded the amount consumed at household level. The milk yields recorded at the MBGs were used as a proxy for total milk yield.

4.3. RESULTS

4.3.1 Overview of productivity traits

Table 4.3 below shows the general overview of production traits in different production systems in the study. Generally some traits showed a wide variation that depicted differences in management and other biological aspects that could not be controlled for. There was a large difference in the magnitude of milk yield traits between the UK and Malawi. For instance average daily milk yield per lactation in Malawi was about 13 litres which was less than half of the average daily milk yield per lactation of about 31 litres in the UK. Also notable was the generally wide variation in the yields in Malawi as depicted by the relatively higher coefficient of variation (CV) mostly between 32% and 42% while in the UK the CVs were between 25% and 29%. The results indicate a wide gap between low and high milk production in Malawi suggesting possibility to improve the low production.

The milk yields from smallholder farms were similar to those of Mapanga Farm which is a large scale commercial farm. Smallholder farms peak milk yields were relatively higher (ranging from 12 to 30 litres/day with a mean of 20.2±5.7 litres/day) than the large scale farm whose peak milk yield ranged from 8 to 27 litres/day and a mean of 18.6±3.8 litres/day.

Body condition scores, weight, energy content, milk protein and calving interval were less variable in all the production systems compared to milk yield. Cows in Malawi had low milk yield and relatively higher body condition scores and body energy content than cows in the UK which could be due to the differences in the genetic merit of the cows and subsequent prioritisation of energy partitioning. The cows in Mapanga had relatively higher body condition scores (3.4) than the cows in smallholder farms (2.7) and the Langhill herd (2.1).

Table 4.3 Milk production traits of Holstein-Friesian cows in UK and Malawi

Variable	Langhill (UK*)		Mapanga (Mw*)		Smallholder (Mw)	
	Mean±SD*	CV*%	Mean±SD	CV%	Mean±SD	CV%
Average daily milk yield (litres/day)	29.4±8.4	29	12.3±4.2	34	14.3±5.5	39
Early lactation milk yield (litres/day)	33.7±8.5	25	12.6±4.8	38	12.8±5.4	42
Mid lactation milk yield (litres/day)	32.2±8.0	25	12.4±4.0	32	14.9±5.5	37
Late lactation milk yield (litres/day)	26.6±7.4	28	11.3±2.9	26	-	-
Milk fat (g/kg)	38±7	17	-		-	-
Milk protein (g/kg)	32±3	11	-		28±2	7
Milk fat protein ratio	1.19±0.18	15	-		-	-
Milk yield acceleration	0.48±0.33	70	-		-	-
Body condition score	2.1±0.4	18	3.4±0.7	19	2.7±0.5	20
Weight (kg)	595±75	13	451±73	16	484±98	20
Body energy content (MJ)	4480±902	20	4625±1055	23	4403±997	23
Calving interval (days)	405±71	18	454±90	20	478±103	22
Days to first recorded heat	66±28	43	144±85	59	85±39	45
Days to first service (days)	71±25	35	144±85	59	104±42	37
Days to first high luteal activity	31±18	59	-		79±29	70
Days to successful service	125±66	52	-	-	-	-

*UK=United Kingdom; Mw=Malawi; CV=coefficient of variation; SD=standard deviation

It is not clear whether the higher body conditions scores in Mapanga Farm were due to management or genotype effect or an interaction of the two. However, the observation that Mapanga cows had body condition scores ranging from 3.0 to 4.25 gave an indication that some cows may have been over conditioned.

Milk yield acceleration (MYA), interval from calving to first high luteal activity (DFHLA) and successful service in the UK herd also had high variability reflecting large differences between production systems as well as individual cows within systems. MYA measures the rate of increase in milk yield per day from initial milk yield to peak milk yield.

Fertility traits in the UK herd were, as expected, better than those in Malawi herds with all the intervals considered being shorter. The DFHLA in Malawi were 79±29 while in the UK they were 31±18 meaning that cows in Malawi spent more than a month and a half more than the cows in the UK before resumption of luteal activity post calving. This suggests that the cows in Malawi have relatively long post-partum anoestrus durations than cows in the UK resulting in the long durations of the other fertility traits considered. The interval from calving to first recorded heat and days to first service (DFS) were the same within the Mapanga herd because only the service date was recorded. For the smallholder farms, days to first recorded heat were captured because of the monitoring study otherwise heat recording was also not in place.

4.3.2 Productivity within production systems

4.3.2.1 Milk production

Table 4.4 below shows means of various milk production traits of the UK Langhill herd at SRUC Dairy Research Centre from dataset 2. The traits were significantly different ($p<0.05$) between production systems showing the importance of both genetic merit and feeding systems. High genetic merit cows under low forage (LFS) had the highest milk production in most of the milk production traits and the longest interval from calving to peak milk yield.

Table 4.4: Milk production traits of high and average genetic merit cows under high and low forage feeding systems at SRUC Dairy Research Centre

Variable	Production system (mean±SEM)			
	HFS* (n=174)	LFS* (n=219)	HFC* (n=235)	LFC* (n=221)
Daily milk yield (litres/d)	27.5±0.09 [a]	35.0±1.0 [b]	24.3±0.1 [c]	30.4±0.1 [d]
Early lactation MY* (litres/d)	32.0±0.2 [a]	38.6±0.2 [b]	29.0±0.2 [c]	35.0±0.2 [d]
Mid-lactation MY (litres/d)	29.8±0.2 [a]	38.6±0.2 [b]	26.4±0.2 [c]	33.5±0.2 [d]
Late lactation MY (litres/d)	24.6±0.1 [a]	32.4±0.1 [b]	21.5±0.1 [c]	27.2±0.1 [d]
Service milk yield (litres/d)	28±7 [a]	37±8 [b]	26±6 [c]	33±8 [d]
First recorded MY (litres/d)	21.8±0.7 [a]	24.7±0.6 [b]	21.7±0.6 [a]	23.9±0.6 [b]
Peak milk yield (litres/d)	39.3±0.5 [a]	48.0±0.6 [b]	36.3±0.5 [c]	43.2±0.5 [d]
Days to peak milk yield	57±2 [a]	65±2 [b]	47±2 [c]	57±2 [a]
Milk fat (g/ kg)	41±0.09 [a]	38±0.08 [a]	39±0.08 [a]	36±0.08 [b]
Milk protein (g/ kg)	33±0.05	33±0.04	32±0.05	31±0.04
Milk fat protein ratio	1.23±0.002 [a]	1.16±0.002 [b]	1.23±0.002 [a]	1.16±0.002 [b]
MYA* (litres/d/d)	0.46±0.03 [a]	0.51±0.02 [b]	0.47±0.03 [a]	0.47±0.02 [a]

[a, b, c, d]Means with different superscript within a row are significantly different ($p<0.05$)

*HFS=high forage select; LFS= low forage select; HFC=high forage control; LFC=low forage control; MY=milk yield; MYA=milk yield acceleration to peak milk yield

This trend was also reflected in Figure 4.1 also from dataset 2, where lactation milk yield is shown. Average genetic merit cows under high forage (HFC) had the lowest milk yields. Although the LFS cows had initial milk yield similar to average merit cows under low forage (LFC), their peak milk yield was significantly different and this was also depicted by the MYA. LFS cows had significantly high MYA meaning that they increased their mobilisation of nutrients towards milk production at a rate that was higher than the rest of the cows in the other systems.

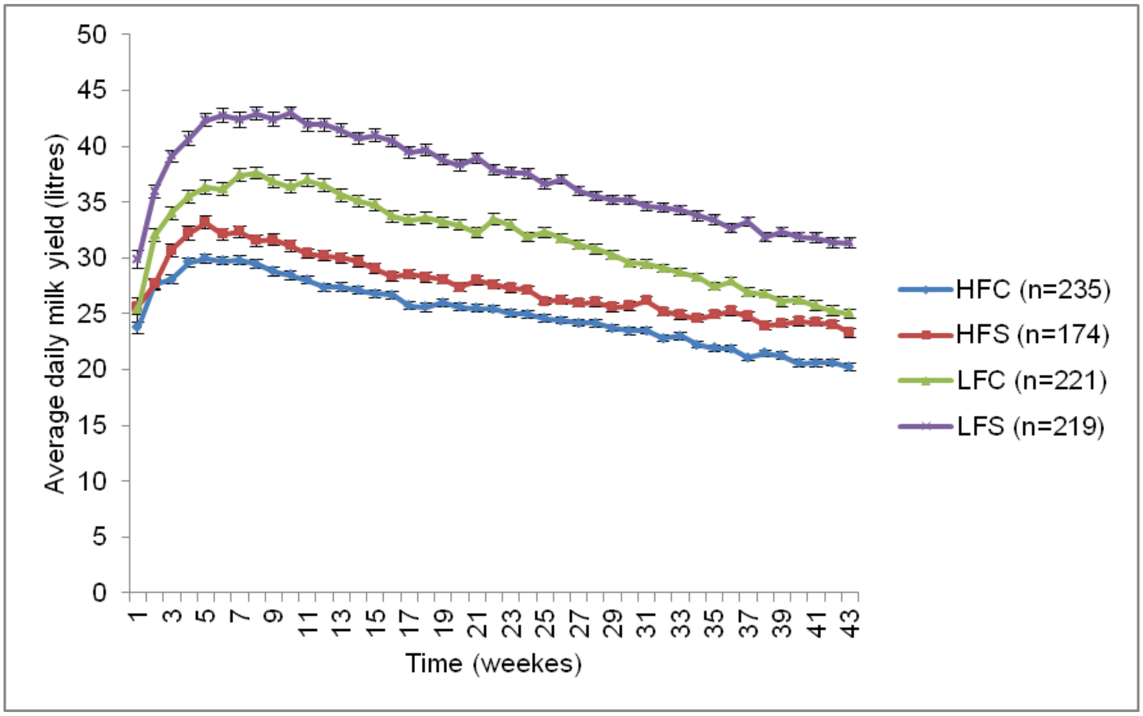

Figure 4.1: Weekly milk yield of high and average genetic merit cows under high and low forage feeding systems at SRUC Dairy Research Centre. (HFS=high forage select; LFS= low forage select; HFC=high forage control; LFC=low forage control)

Table 4.5 shows productivity traits of cows in smallholder farms that were fed either maize bran or dairy mash as a concentrate. Both baseline survey and monitoring study results showed that cows fed maize bran had significantly ($p<0.05$) lower milk yield during early and peak lactation reflecting the differences in the nutrient content of the concentrates.

Table 4.5: Productivity traits in smallholder dairy cows fed either dairy mash or maize bran

Variables	Type of concentrate (mean±SEM)			
	Baseline survey		Monitoring study	
	Dairy mash	Maize bran	Dairy mash	Maize bran
Milk yield (litres/d)			14.2±0.2 (17)	13.4±0.4 (4)
Early lactation milk yield (litres/d)	12.7±1.0^{a} (29)*	10.8±2^{b} (6)	16.7±4.4^{a} (17)	10.1±4.0^{b} (4)
Peak milk yield (litres/d)	20.9±1.4^{a} (28)	15.5±2.5^{b} (6)	18.4±1.4^{a} (17)	13.1±2.1^{b} (4)
Late lactation milk yield (litres/d)	7.8±1.0^{a} (28)	10.2±3.1^{a} (5)	-	-
Milk protein (g/kg)	-	-	28±0.5	28±0.6
Body condition score	-	-	2.9±0.02^{a}	2.1±0.03^{b}
Weight (kg)	-	-	523±4^{a}	472±6^{b}
Body energy content (MJ)	-	-	4716±36^{a}	3495±60^{b}
Calving interval (days)	494±38^{a} (8)	434±52^{b} (3)	-	-
Calving to 1st observed heat (days)	-	-	77±9^{a} (15)	121±17^{b} (3)
Calving to service interval (days)	111±5 (9)	277 (1)	106±12 (12)	77 (1)
Calving to 1st high luteal activity (days)	-	-	75±7^{a} (21)	90±9^{b} (7)

^{a,b} Means with different superscripts within same row and study were different ($p<0.05$) *Figures in parenthesis indicate the sample size

The average crude protein and gross energy levels in maize bran were 89 g/kg and 14.1 MJ/kg while for dairy mash it was 194 g/kg and 16.9 MJ/kg, respectively (Table 4.6). There was no significant difference between milk protein content with the type of concentrate used.

Table 4.6: Feed Composition of the feeds for dairy cows at Bunda College and smallholder farms

Composition	Feed type (mean±SD)*			
	Grass	Legumes	Dairy mash	Maize bran
Dry matter (%)	86.2±5.3	91.3±0.6	88.7±1.9	88.3±1.9
Crude protein (g/kg)	89±9	197±6	194±26	89±11
Gross Energy (MJ/kg)	9.1	-	16.9	14.1
Ash (%)	8.8±0.5	6.7±0.6	8.2±3.2	5.7±0.3

*Duplicate samples analyzed were from three different batches of feed collected from Bunda College. These samples were from feeds common to both Bunda and surrounding smallholder dairy farms.

Figure 4.2 below shows average daily milk yields in the smallholder farms. The graph shows that milk yield from farms using dairy mash was not always more than for those farms largely using maize bran. The results may reflect the inconsistent use of the type of concentrate on the farm. Generally the shapes of the lactation curve indicate fluctuation in milk yield which may have been corresponding to changes in the feeding of the cows.

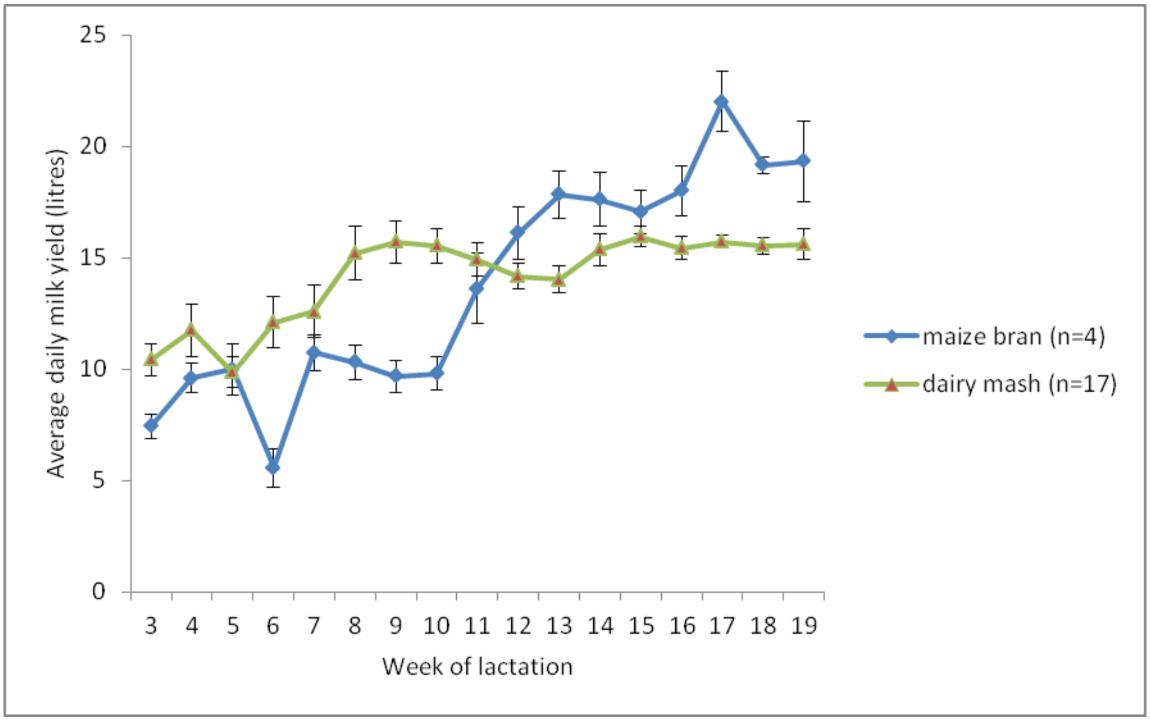

Figure 4.2: Average daily milk yields for Holstein cows in smallholder farms using either maize bran or dairy mash as a concentrate.

Milk yield in the three feeding groups at Mapanga varied widely between cows and the highest milk yield achieved during the study period was 27 litres per day while the lowest was about half a litre per day. Table 4.7 below shows the average daily milk yield, fertility traits and BEC during the study period.

Table 4.7: Least square means for milk yield and fertility in low, average and high milk producing Holstein cows at Mapanga Farm

Variable	Low	Average	High
Average milk yield (litres/day)	8.2±0.5^{a} (14)	11.8±0.3^{b} (31)	15.1±0.4^{c} (16)
Body energy content (MJ)	4362±73^{a} (14)	4635±43^{b} (31)	4744±53^{c} (16)
Calving interval (days)	465±8^{a} (9)	442±4^{b} (23)	449±5^{c} (15)
Days to service	58±4 (4)	55±3 (9)	62±5 (3)

^{a,b,c} Means with different superscripts within the same row are significantly different (p<0.05) *Figures in parenthesis show the sample size; SE= standard error

The average milk yields over time showed that generally the milk yield declined throughout the study period (Figure 4.3) and hence the curve did not form the typical lactation curves suggesting the need to review the feeding system and other management factors at the farm.

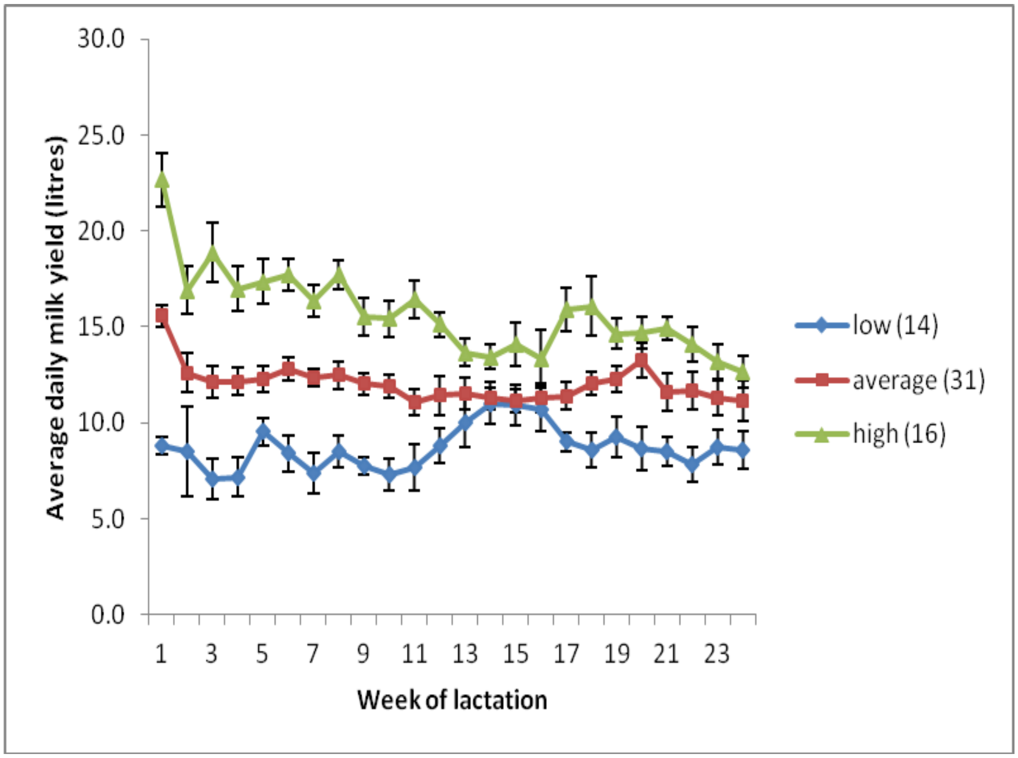

Figure 4.3: Weekly milk yield of low, average and high producing Holstein cows at Mapanga Dairy Farm (error bars= standard error)

4.3.2.2 Body energy content

Results from dataset 2 also showed that cows under low forage in the Langhill herd had significantly ($p<0.05$) higher body energy content (BEC) than those fed high forage diet almost throughout the lactation. This trend is also reflected in Figure 4.4 where lactation BEC is shown. Cows under high forage had lower BEC translating to lower milk yield as discussed above.

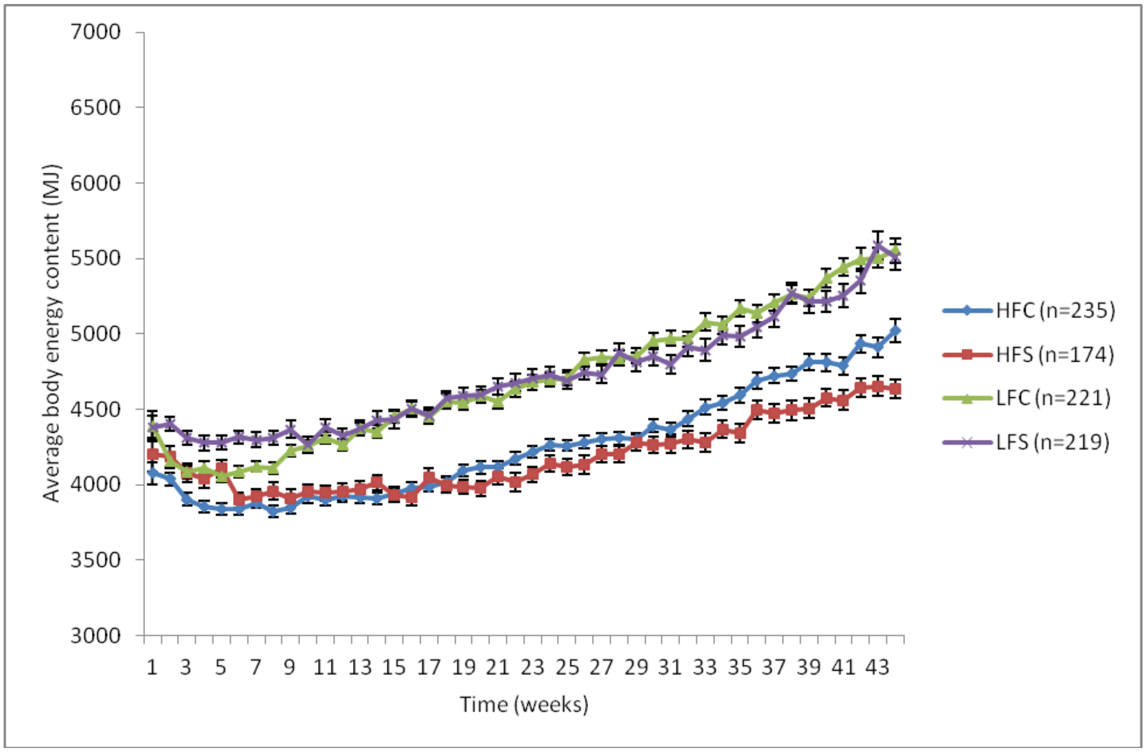

Figure 4.4: Average weekly body energy content (MJ) during the lactation period of high and average genetic merit cows under high and low forage feeding systems at SRUC Dairy Research Centre. (HFS=high forage select; LFS= low forage select; HFC=high forage control; LFC=low forage control; error bars =standard error of the mean)

Figure 4.5 further shows that the high genetic merit cows under high forage had BEC that did not exceed the average of the first three weeks after calving until after about 42 weeks while the rest of the cows had done so by 22 weeks after calving.

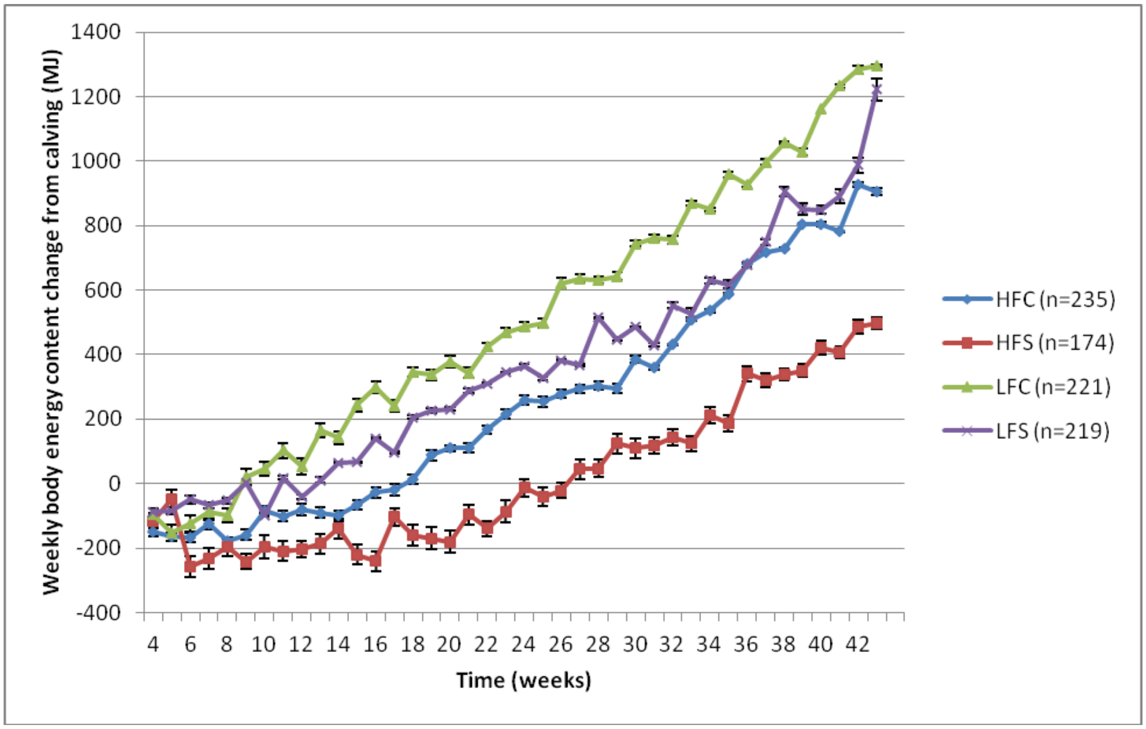

Figure 4.5: Difference in body energy content (MJ) between weekly and the average of the first three weeks after calving in cows of high and average genetic merit under high and low forage feeding systems at SRUC Dairy Research Centre. (HFS=high forage select; LFS= low forage select; HFC=high forage control; LFC=low forage control; error bars =standard error of the mean)

Results from dataset 1 also showed differences in BEC between production systems which was reflected in milk yield at service and percent BEC change between calving and service (Table 4.8). The lowest BEC post calving was on days 64, 76, 85 and 103 for LFC, LFS, HFC and HFS cows, respectively with respective energy loss of 18, 20, 23 and 28%. The results show that high genetic merit cows had the highest duration and magnitude of energy loss within each feeding system. However, the duration to nadir BEC was variable within feeding systems with the median in each system being much lower than the average. The median was 44, 52, 59 and 91 days for LFC, LFS, HFC and HFS cows, respectively

Table 4.8: Changes in body energy content and milk yield within the lactation period of high and average genetic merit cows under high and low forage feeding systems at SRUC Dairy Research Centre

Variables	Production system			
	HFC* (n=235)	HFS (n=174)	LFC (n=221)	LFS (n=219)
Initial MY* (litres/day)	23.6±0.7[a]	24.6±1.0[a]	25.8±1.3[b]	29.2±1.0[c]
Peak MY (litres/day)	32.8±0.5[a]	35.2±0.6[b]	39.8±0.7[c]	46.0±0.7[d]
Days to peak milk yield	69±4[a]	77±5[b]	70±3[a]	82±4[b]
MYA* (litres/day)	0.17±0.02[a]	0.26±0.03[b]	0.26±0.02[b]	0.31±0.03[c]
Initial BEC* (MJ)	4077±74[a]	4199±115[a]	4387±101[b]	4381±76[b]
Nadir BEC (MJ)	3323±40[a]	3275±52[a]	3650±46[b]	3673±54[b]
Days to nadir BEC	88±5[a]	106±6[b]	68±5[c]	83±6a
Milk yield at nadir BEC	26.5±0.5[a]	27.9±0.6[b]	33.2±0.7[c]	38.1±0.7[d]
% BEC change to nadir	-19.6±1.6[a]	-26.9±1.8[b]	-15.0±1.5[c]	-18.3±1.5[a]
% BEC change to service	-6.8±1.0[a]	-10.6±1.3[b]	0.6±1.4[c]	-2.7±1.3[d]

[a,b,c,d] Means with different superscripts within the same row are significantly different ($p<0.05$); *HFC=high forage control; HFS=high forage select; LFS= low forage select; LFC=low forage control; MY=milk yield; MYA=milk yield acceleration to peak milk yield; BEC= body energy content

LFC cows were in positive energy balance at service. However, there was a wide variation among the LFC cows as depicted by a standard error greater than the mean. The median was 1.6%. The results indicate that some (53%) LFC were still in negative energy balance while others (47%) were in positive energy balance. The other systems had far fewer cows that were in positive energy balance (20, 27 and 40% for HFS, HFC and LFS cows, respectively). The interval to peak milk yield in cows under high forage was much shorter that their interval to nadir BEC. However, both intervals were similar for low forage cows.

Similar results were also found in the by-product and home grown feeding system in dataset 3 (Figure 4.6) where cows on home grown feeds were in negative cumulative energy balance almost throughout the lactation period. BPC and BPS cows had returned to positive energy balance by weeks 25 and 28, respectively. Nadir energy balance was earliest in BPC cows at 7 weeks lactation followed by BPS cows at 10 weeks lactation. Cows on home grown feeds took much longer to reach nadir energy balance.

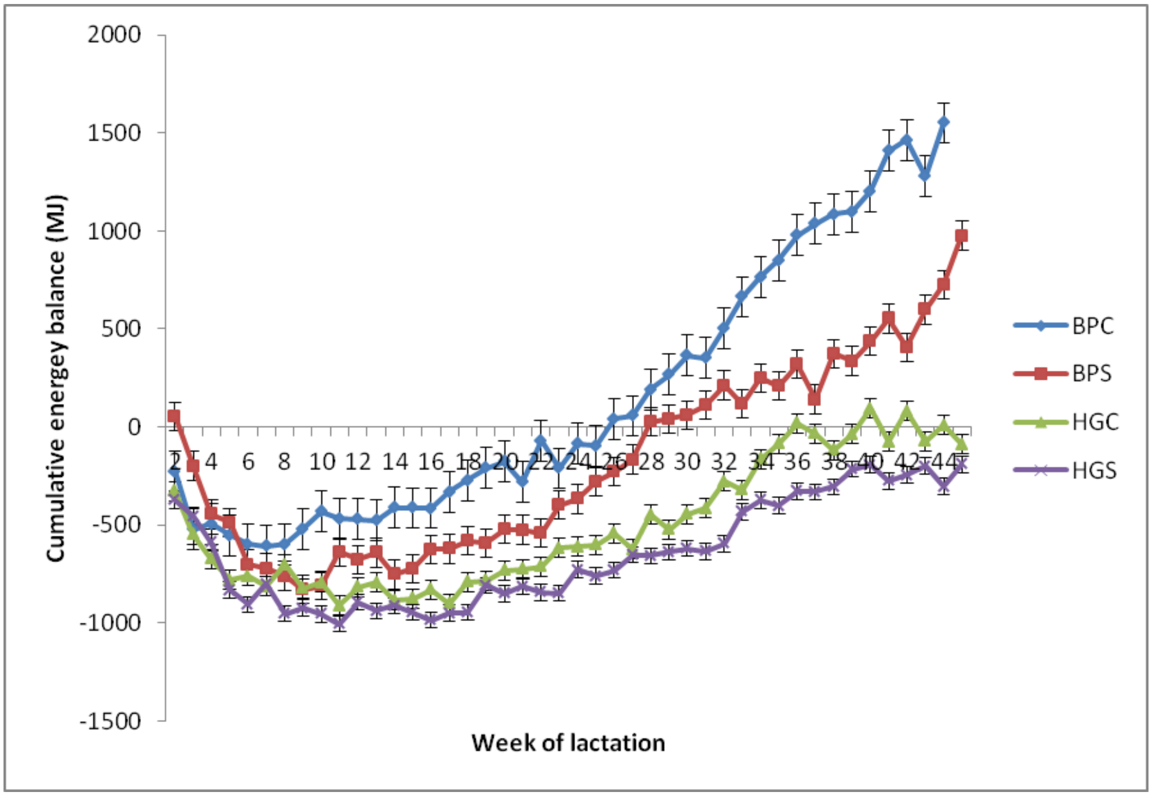

Figure 4.6: Cumulative energy balance for high and average genetic merit cows fed either home grown of by product feeds at SRUC Dairy Research Centre. (BPC=by-product control; BPS= by-product select; HGC=home-grown control; HGS=home-grown select)

The overall BEC in cows from Mapanga Farm were significantly different ($p<0.05$) between the low and high producing cows with high producing cows having higher overall BEC (Table 4.7). However, the BEC curve did not have any specific pattern throughout the lactation in all the cow groups unlike the cow from the Langhill herd (Figure 4.7). This may be reflecting the need to review the feeding system at Mapanga Farm in order to improve productivity.

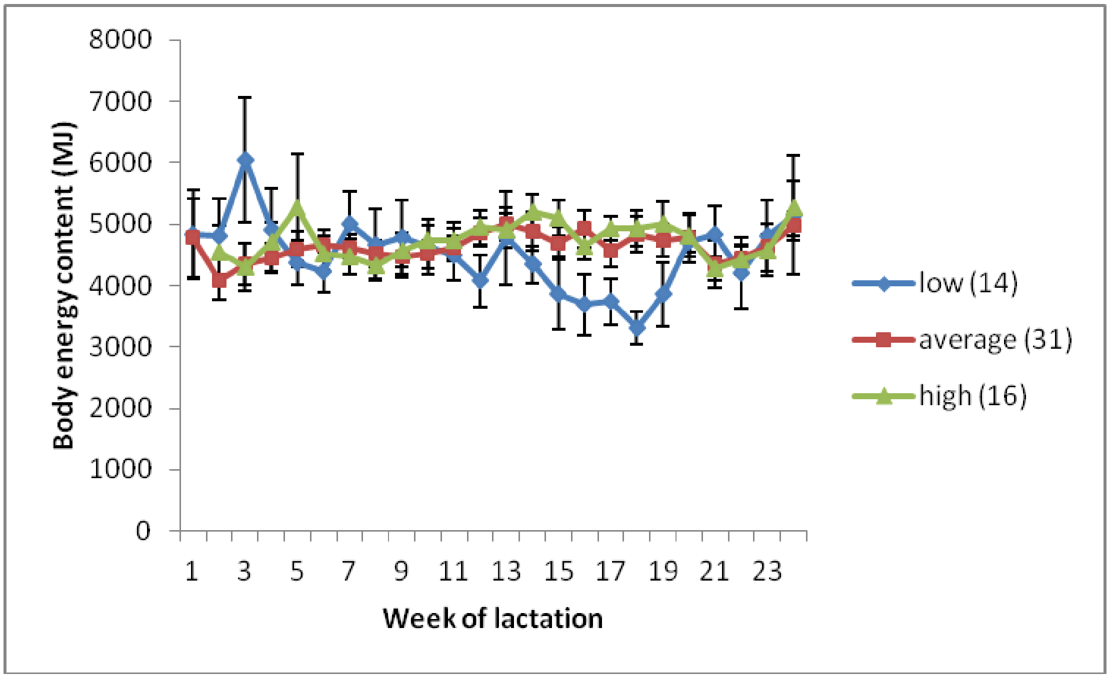

Figure 4.7: Weekly body energy content of low, average and high producing Holstein cows at Mapanga Dairy Farm. (error bars=standard error of the mean)

Cows in the smallholder farms did not show a specific pattern in the weekly BEC although cows on dairy mash had higher overall ($p<0.05$) BEC than cows on maize bran (Table 4.5). The lack of a specific pattern could reflect the switch between use of maize bran and dairy mash in feeding the cows.

Considering BEC in relation to milk yield all production systems showed that the BEC ranges were similar although milk yield was much lower in Mapanga and smallholder farms than in cows from the Langhill herd (Figure 4.8). Considering the amount of milk produced in Malawi farms, the results suggest that cows in Malawi were more biased towards deposition of nutrients in body reserves than milk production.

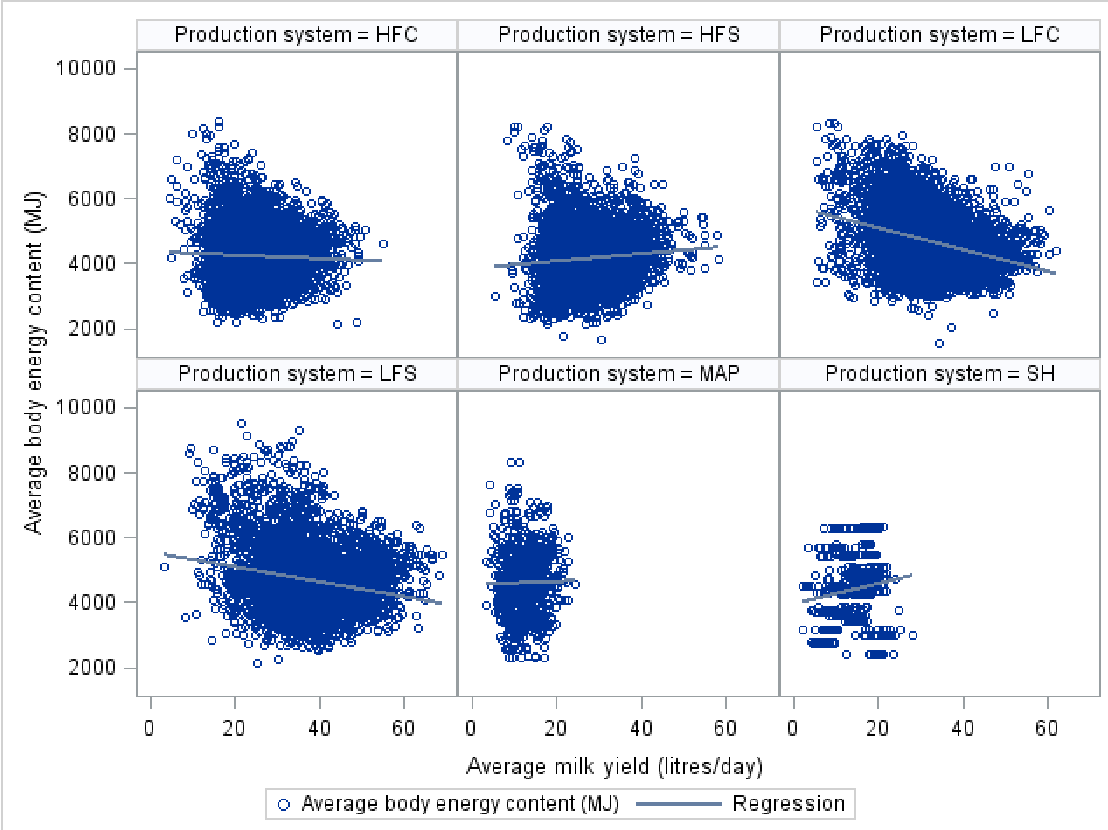

Figure 4.8: Lactation body energy content and milk yield of dairy cows in Malawi farms (Smallholder & Mapanga) and the Langhill herd in the UK; HFC=high forage control; HFS=high forage select; LFS= low forage select; LFC=low forage control; MAP=Mapanga; SH=Smallholder farms

4.3.2.3 Fertility

Results from dataset 1 showed that the calving and service BCS, number of days to first recorded heat (DFH) and first service (DFS) were similar (p>0.05) between production systems in the Langhill herd (Table 4.9). However, there were significant differences (p<0.05) in calving and service weights, body energy content, number of days to first high luteal activity (DFHLA), successful service (DSS) and calving interval. High genetic merit cows had longer DSS and calving intervals than cows of average genetic merit. LFC cows had the shortest DFHLA while LFS had the longest.

Table 4.9: Fertility traits (mean±SEM) of high and average genetic merit cows under high and low forage feeding systems at SRUC Dairy Research Centre

Variable	Production system			
	HFS* (n=174)	LFS* (n=219)	HFC* (n=235)	LFC* (n=221)
Calving weight (kg)	593±0.9 ^{a}	602±0.7 ^{a}	564±0.6^{b}	569±0.6 ^{b}
Service weight (kg)	578±0.8 ^{a}	613±0.8 ^{b}	562±0.6^{c}	592±0.7 ^{d}
Calving BCS*	2.3±0.003	2.3±0.003	2.3±0.003	2.3±0.003
Service BCS	2.0±0.003	2.2±0.004	2.1±0.003	2.3±0.004
Calving BEC* (MJ)	4670±10 ^{a}	4741±8 ^{a}	4354±7 ^{b}	4496±7 ^{a}
Service BEC (MJ)	4114±8 ^{a}	4662±10 ^{b}	4440±7 ^{a}	4633±9 ^{c}
% BEC change	-10.3±0.2 ^{a}	-0.6±0.2 ^{b}	-4.2±0.2 ^{b}	4.2±0.2^{c}
DFHLA	30±2^{a}	35±3 ^{b}	30±3 ^{a}	27±2 ^{c}
Days to first recorded heat	70±2	69±2	66±2	60±2
Days to first service	73±2	73±2	72±2	68±1
Days to successful service	132±5 ^{a}	132±5 ^{a}	119±5 ^{b}	119±4 ^{b}
Calving interval (days)	414±4 ^{a}	408±4 ^{b}	403±4 ^{c}	396±4 ^{d}

^{a,b,c,d}Means with different superscripts within the same row are significantly different ($p<0.05$)

*BCS=body condition score; BEC= body energy content; DFHLA= days to first high luteal activity; HFC=high forage control; HFS=high forage select; LFS= low forage select; LFC=low forage control

High genetic merit cows also had higher calving weights than cows of average genetic merit. Service weights had a slightly different trend where LFS cows were heavier while HFC cows were lighter. A similar trend was observed on service BEC. These characteristics were also similar in the whole lactation trend shown in Figures 4.4 to 4.5 above.

Considering the change in BCS between calving and service showed that most cows (56%) had moderate BCS loss which was between 0.25 and 0.75 while about 15% had BCS gain of up to 0.5. About 23 % of the cows neither gained nor lost body condition. Cows that neither gained nor lost body condition had significantly ($p<0.05$) longer DFH than cows that lost up to 0.75 of their calving BCS. However, the DFH of these cows was not significantly different from cows that gained up to 0.75 BCS. Only a few cows (3%) gained BCS of more than 0.5 and these were mostly average genetic merit cows under low forage while there were also a few (4%), mostly high genetic merit cows, that lost BCS of more than 1. The results show that there were a few outliers in all four systems that had either longer or shorter DFH with change in their BCS between calving and service (Figure 4.9). The results may be reflecting adjustments by these few individual cows to body nutrient demand.

The effect of BCS change between calving and service on DFH showed an significant ($p<0.05$) interaction with production system (Figure 4.9). The BCS change had no significant effect on DFH of LFC, LFS and HFC cows while in HFS cows DFH increased with increase in BCS change. In some of cows, DFH increased with BCS gain of more than 0.5 suggesting a negative effect of BCS gain beyond 0.5. However, there were also some cows that did not follow this trend.

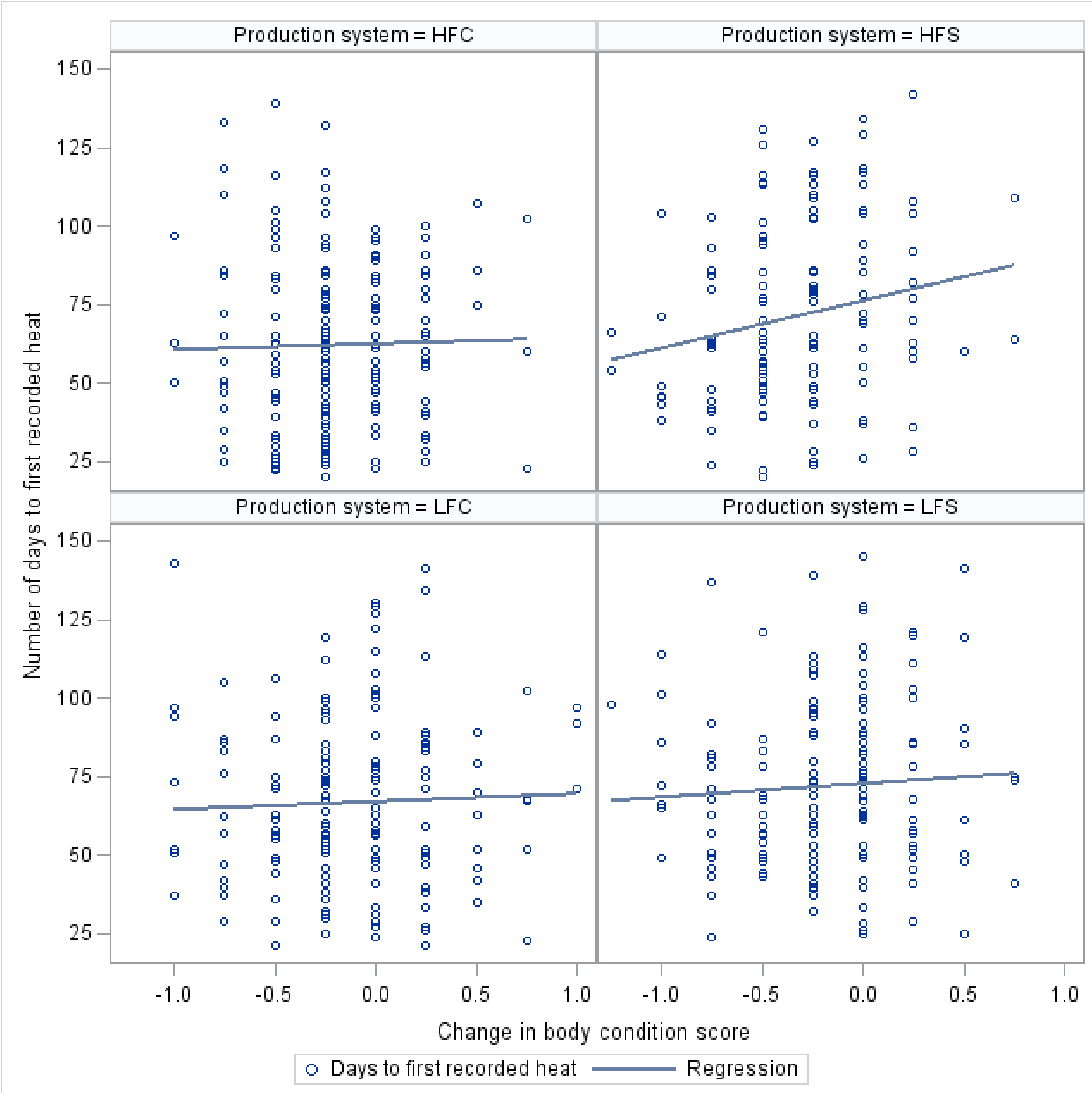

Figure 4.9: The relationship between days to first recorded oestrus and the change in body condition score between calving and service at SRUC Dairy Research Centre. * HFC=high forage control; HFS=high forage select; LFS= low forage select; LFC=low forage control

Under smallholder farms in Malawi, only 18 out of 28 cows had observable heat during the study period and only 13 were inseminated. However, milk progesterone measurements showed cyclicity in all the cows. There was no correlation ($p>0.05$) between days to first high luteal activity (DFHLA) and days to first observed heat (DFOH). This may be an indication of poor heat detection or that some cows were undergoing silent heat. From the baseline survey, only 11 farms provided data on calving interval and 8 of these used dairy mash as a concentrate for the cows. Table 4.5 also shows that most of the cows that were observed on heat and inseminated were from farms that used dairy mash as a concentrate.

When further comparisons were made based on how farms managed the cows in terms of housing hygiene and feed levels, there were some significant differences ($p<0.05$) in fertility traits (Table 4.10). There were fewer cows from farms with low hygiene and feeding levels that had DFOH and DFS reported. Cows that had higher feeding level had significantly lower DFOH and DFHLA. However, there was a significant interaction ($p<0.05$) between feeding level and housing hygiene as well as between housing hygiene and the type of concentrate fed to the cows.

A smaller number of cows were inseminated than those observed on heat for farms with low hygiene while all cows observed on heat were inseminated in farms with high hygiene.

Table 4.10: Cow fertility traits in smallholder farms with different management levels

Trait			Mean ± SEM		
			DFOH	DFS	DFHLA
Management category	Housing hygiene	Low	81±31^{a} (3)*	218^{a} (1)	74±25 (3)
		Average	79±13^{a} (10)	92±10^{b} (7)	80±6 (15)
		High	98±11^{b} (5)	97±11^{b} (5)	79±11 (10)
	Feeding level	Low	102±7^{a} (2)	108^{ab} (1)	85±13^{a} (4)
		Average	95±16^{a} (7)	112±22^{a} (6)	86±11^{a} (11)
		High	73±13^{b} (9)	94±12^{b} (6)	71±6^{b} (13)

^{a,b} Means with different superscripts within the same column and management category are significantly different (p<0.05) *Figures in parenthesis indicate the sample size; DFOH= days to first observed heat; DFS= days to first service; DFHLA= days to first high luteal activity

Cows under low housing hygiene had significantly longer DFS (p<0.05) than those under high housing hygiene. One cow was inseminated indicating that the rest of the cows under low housing hygiene had even longer DFS.

A comparison between the similar fertility traits in the Langhill herd shows that cows in the smallholder farms regardless of management level had longer DFOH, DFH and DFHLA intervals by 19, 33 and 48 days respectively. The shortest DFHLA interval in smallholder farms was 71 days and was in farms with high feeding levels. This was almost 2-times longer than the longest DFHLA interval in the Langhill herd which was in cows of high genetic merit under high forage.

The age at first service at Mapanga Dairy Farm was 1.6±0.3 years while age at first calving was 2.4±0.3 years. These ages were similar to those of the Langhill herd which were 1.3±0.1 and 2.1±0.2, respectively. However, the cows at Mapanga had a wide variation in the number of days to service (Table 4.11) with an average of 169 days. Records also showed that some cows were served before the VWP of 60 days elapsed with cows being served as early as 26 days postpartum. A similar observation was made during the monitoring study where 50% of the 16 cows served were served before the end of VWP (Table 4.11). The days to service for these eight cows varied from 15 to 44 days. This observation suggests that though animal recording is practiced on the farm, records are not used in farm routine decision making.

Table 4.11: Fertility traits of cows at Mapanga Dairy Farm

Variable		n	Mean±SD	Median	Minimum	Maximum
Existing farm data	Age at first service (years)	33	1.6±0.3	1.6	1.0	2.0
	Age at first calving (years)	66	2.4±0.6	2.3	1.6	4.7
	Days to service	98	169±90	163	26	447
	Calving interval	96	454±90	446	311	732
Monitoring study	Days to service	16	62±41	44	15	194
	Calving interval (days)	49	457±99	452	306	844

Data on expected calving dates showed that there was both over- and under-estimation of the expected calving dates. Based on records the estimated calving interval was 495 days with a maximum of 791 days. The farm reported that they made estimates using 285 days as the gestation period and when re-estimation was done the results showed that the CI was 454±90 days with a maximum of 732 days.

Several animals had not been served at the time of data recording and they had an average of 128 days post-partum. This may be an indication of problems with reproductive management at the farm which could be genuinely due to non-return to oestrus or problems with heat detection and timely insemination.

Analysing the fertility of the cows based on their consistency to remain in one feeding group showed that cows that consistently remained in one group took significantly ($p<0.05$) more days to be served than cows that changed from one group to another. There was no significant effect on calving interval. However the cows that were inseminated were much fewer (26%) than the cows that were monitored. The average number of days from calving to end of the monitoring for the cows not served (74%) was 128±43, ranging from 71 to 221 days.

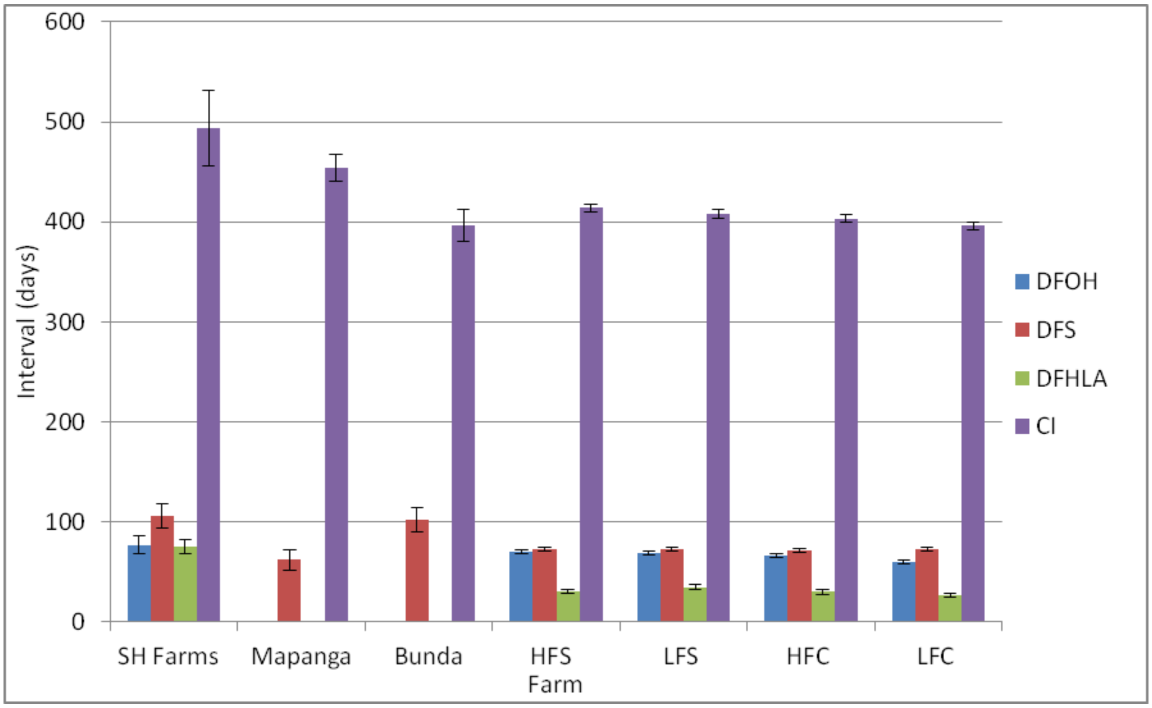

Figure 4.10: Fertility traits of dairy cows in Malawi farms and the Langhill herd in the United Kingdom (DFOH= days to first observed heat, DFS=days to first service; DFHLA=days to first high luteal activity, CI=calving interval)

Figure 4.10 shows that generally cows in Malawi had longer intervals for all the fertility traits considered. Cows from smallholder farms had long post-partum anoestrus durations that were almost twice those of the UK cows. These differences were consistent with differences in feeding systems and fertility management. There was also higher variability in the fertility traits in Malawi indicating possibility for improvement through appropriate management and selection.

4.3.2.4 Cow activity

Cow activity in both the UK and Malawi farms varied with the feeding system used. Results from dataset 3 showed that Langhill herd cows on home grown feeds were significantly ($p<0.05$) more active than cows on by-product feeds as indicated by higher motion index and number of steps per day (Table 4.12). Within feeding systems, high genetic merit cows were more active than average genetic merit cows.

Table 4.12: Least square means for average daily activity, feeding duration and milk yield of high and average genetic merit cows on either home grown or by-product feeds at SRUC Dairy Research Centre

Variables	Production system (mean±SEM)			
	*BPC (n=31)	BPS (n=36)	HGC (n=35)	HGS (n=26)
Number of steps	1332±20^{a}	1319±23^{a}	6140±86^{b}	6344±177^{b}
Motion index	4947±15^{a}	5166±37^{b}	5993±36^{c}	6250±40^{d}
Standing duration (hrs)	12.2±0.02^{a}	11.9±0.04^{a}	13.3±0.04^{b}	13.4±0.04^{b}
Lying duration (hrs)	11.8±0.03^{a}	12.1±0.03^{a}	10.7±0.02^{b}	10.6±0.03^{b}
No. of lying bouts	10.2±0.5	11.1±0.5	10±0.4	11±0.7
Minimum lying bout duration (hrs)	0.26±0.02	0.22±0.01	0.21±0.01	0.20±0.01
Maximum lying bout duration (hrs)	2.53±0.09^{a}	2.43±0.09^{a}	2.00±0.06^{b}	1.93±0.07^{b}
Eating time (hrs)	4.6±0.13^{a}	4.6±0.16^{a}	5.1±0.13^{b}	5.6±0.32^{b}
Body energy content (MJ)	4710±61^{a}	4298±56^{b}	4130±57^{c}	3872±70^{d}
Milk yield (litres)	31.0±0.4^{a}	35.5±0.5^{b}	24.4±0.5^{c}	23.6±0.9^{c}

^{a,b} Means with different superscripts within the same row are significantly different ($p<0.05$); *BPC = by-product control; BPS = by-product select; HGC = home-grown control; HGS = home-grown select

All the cows had a similar number of lying bouts and the duration of the minimum lying bouts. However, cows on by-product feeds had significantly ($p<0.05$) longer duration of maximum lying bouts (about 2½ hours) than cows on home grown feeds (about 2 hours). Cows on home grown feeds also stood almost 1 hour longer than those on by product feeds for both genetic groups. This trend was also shown on time spent eating where cows on home grown feeds spent at least ½ an hour more eating per day than cows on by product feed.

The results also showed that there was an association between energy balance and cow activity. Cows in negative energy balance were less active and produced more milk than those in positive energy balance (Table 4.13). However, there was an interaction between production system and energy balance with regard to feeding duration for BPC and HGS cows. BPC cows in NEB had longer feeding duration (4.9 hrs) than BPC cows in positive energy balance (4.2 hrs). On the hand, HGS cows in NEB had a shorter duration (5 hrs) of feeding that HGS cows in positive energy balance (6 hrs).

Generally, there were relatively wider variations within production systems on cow activity, energy balance and feeding durations with coefficients of variation ranging from 38 to 49% suggesting that there were other differences in cow activity, energy balance and feeding duration associated with individual cows within systems. Such differences will need further detailed analysis of individual cow behaviours within production system.

Table 4.13: The association between energy balance and cow activity in high and average genetic merit cows on either home grown or by-product feeds at SRUC Dairy Research Centre

	Energy balance	
Variable	Negative	Positive
No of steps	1448±12[a]	1512±26[b]
Motion index	5440±47[a]	5823±105[b]
Standing duration (hrs)	13.2±0.07[a]	12.9±0.12[a]
Daily milk yield (litres per day)	31±1.6[a]	26±0.7[b]

The results from Bunda College Farm showed a significant interaction ($p<0.05$) between breed and the type of concentrate fed to the cows. Generally Holstein x Malawi Zebu cows were more active than Holstein cows. Holstein cows fed maize bran had a significantly lower daily motion index and numbers of steps than the rest of the cows (Table 4.14). However, the Holstein cows on maize bran had significantly longer standing duration than Holstein cows on dairy mash. All the cows had a similar number of lying bouts per day but they differed in the duration of the lying bouts. Holstein cows on dairy mash had significantly longer duration of lying bouts than the rest of the cows.

Table 4.14: Daily activity of lactating Holsteins and Holstein x Malawi Zebu crosses fed either dairy mash of maize bran at Bunda College

	Holstein		Crosses	
Variable	Dairy mash	Maize bran	Dairy mash	Maize bran
Number of steps	1250 ± 107^{ab}	971 ± 111^{a}	1643 ± 195^{b}	1804 ± 388^{b}
Motion index	5509 ± 485^{ac}	4091 ± 485^{b}	6706 ± 851^{c}	7489 ± 1701^{c}
Standing duration (hrs)	14.2 ± 0.3^{a}	14.8 ± 0.2^{b}	14.8 ± 0.6^{b}	15.6 ± 0.5^{b}
Lying duration (hrs)	9.8 ± 0.3^{a}	9.2 ± 0.2^{b}	9.2 ± 0.6^{b}	8.4 ± 0.5^{b}
Number of lying bouts	6.4±0.3	5.5±0.2	6.2±0.7	7.0±0.4

Means with the different superscripts within the same row are significantly different ($p<0.05$)

The motion index of Holstein cows fed dairy mash was mostly above that of cows fed maize bran. The motion index was also able to depict the daily routine in the management of the cows. The figure 4.11 shows two major peak periods of activity in the morning and in the afternoon around 6 a.m. and 3 p.m., respectively. These peak periods were the times for morning and afternoon milking. Figure 4.11 further shows that the cows were more active during the day than at night.

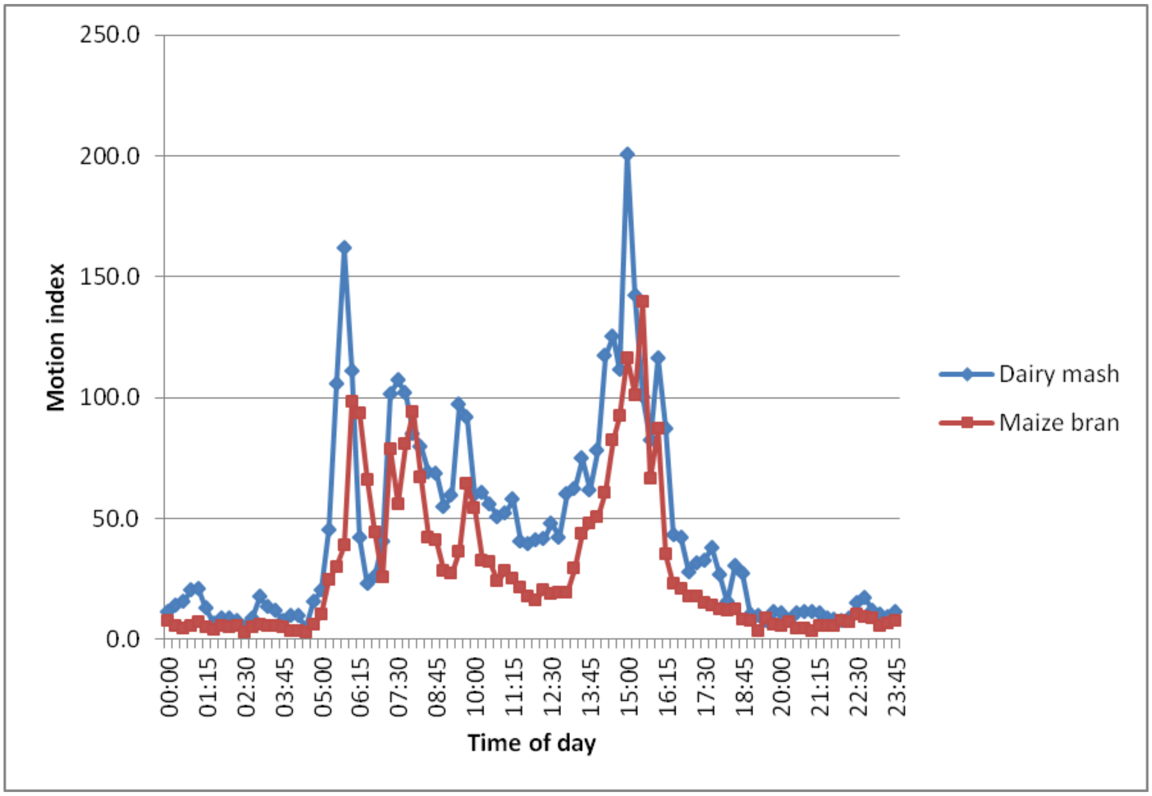

Figure 4.11: Average daily motion index for Holstein cows fed either dairy mash or maize bran as a concentrate at Bunda College

Data from smallholder farms showed that cows fed more of maize bran were relatively more active than those on more of dairy mash (Table 4.15). Cows fed on more maize bran had a significantly higher ($p<0.05$) motion index and number of steps per day. These results were different from those from Bunda where Holstein cows on dairy mash were more active. However, the duration of standing and lying per day was similar between Bunda and smallholder cows.

Table 4.15: Daily activity of Holstein cows in smallholder farms under different management levels

Variable	Management (mean±SEM)					
	Pen hygiene		Feeding level		Type of concentrate	
	Poor	Good	Low	High	Maize bran	Dairy mash
No. of steps	1032±42[a]	677±21[b]	812±27[a]	1150±71[b]	1136±103[a]	892±64[b]
Motion index	4469±181[a]	2859±89[b]	3481±117[a]	4990±307[b]	4864±452[a]	3854±280[b]
Standing time (hrs)	15.0±0.1	14.5±0.2	14.8±0.2	14.9±0.1	15.2±0.3	14.9±0.1
Lying time (hrs)	9.0±0.1	9.5±0.2	9.2±0.2	9.1±0.1	8.8±0.3	9.1±0.1
No. of lying bouts/day	8±0.2a	12±0.6b	9±0.3	8±0.2	10±0.7	8±0.3

[a,b] Means with different superscripts within the same row and management are significantly different ($p<0.05$)

Further, it was found that activity was also related to housing management. Cows in housing that was less hygienic had higher motion index than those in more hygienic housing. The high activity in less hygienic farms could have been an indication of discomfort as pens less cleared of dung attract flies resulting in more tail swishing and stomping of feet. There were also fewer lying bouts in less hygienic pens which could be attributed to the discomfort.

Cows from both low and high hygiene pens spent more time (about 15 hours) standing than lying (9hrs) similar to the cows at Bunda College. Using a day light duration of 11½ hours which is prevalent in May, starting from 6.00 a.m. to 5.30 p.m., it was found that the cows were more active during the day than the night with cows on maize bran and those under poor hygiene still having higher activity.

At Mapanga Dairy Farm, low producing cows had significantly higher ($p<0.05$) total daily motion index, number of steps and duration of standing than average producing cows (Table 4.16). However, these variables were not significantly different from cows in the high producing group. The daily standing durations for low, high and average producing cows were 17.2, 16.8 and 16.3 hours, respectively. These durations were longer than those at Bunda College and the smallholder farms. The average number of lying bouts per day was similar for average and low producing cows, and significantly higher in high producing cows. Low producing cows were those that produced less than 10 litres of milk per day and were fed 5 kg of concentrate per day. The high activity could be associated with spending more time grazing as they had access to less energy from concentrates.

Table 4.16: Daily activity of low, average and high milk producing Holstein cows at Mapanga Dairy Farm

Variable	Milk group		
	Low (5)	Average (9)	High (4)
No. of steps	3675 ± 75^{b}	3529 ± 53^{a}	3588 ± 78^{ab}
Motion index	14159 ± 304^{b}	13554 ± 208^{a}	13855 ± 333^{ab}
Standing duration (hrs)	17.2 ± 0.2^{b}	16.3 ± 0.1^{a}	16.8 ± 0.2^{c}
Lying duration (hrs)	6.7±0.1	7.7±0.1	7.2±0.2
No. of lying bouts	6.6 ± 0.2^{a}	6.5 ± 0.1^{a}	7.5 ± 0.2^{b}

^{a,b} Means with different superscripts within the same row are significantly different

High producing cows also had high activity although they were receiving more than the recommended amount of concentrate. They may have been spending more time grazing in order to optimise their forage intake and maintain their high milk production. High producing cows also had more lying bouts than the other cows suggesting that they lay down several times, probably for shorter durations, to rest and stood again to continue grazing. Average producing cows may have been getting adequate nutrients to meet the average level of milk production and hence had more time to lie down and rest.

Comparing activity during the day and the night showed that all the cows were more active during the day than the night with level of activity between groups following a trend similar to the overall day activity explained above. Generally, the cows had significantly higher ($p<0.05$) motion index, number of steps, lying bouts and longer standing duration (Table 4.17) during the day than the night. This is because cows had access to grazing and were milked during the day while they were enclosed in pens at night. This routine is also depicted in Figure 4.12 which shows the overall cow activity (motion index) throughout the day. In addition the results indicated that night activity was more allocated towards lying down than standing. However, low producing cows allocated almost equal time between lying and standing during the night as they probably continued to feed.

Table 4.17: Day and night activity of Holstein cows at Mapanga Dairy Farm

Variable	Time of day	Milk group		
		Low	Average	High
	n	5	9	4
No. of steps	Day	3436±92[b]	3216±54[a]	3260±75[c]
Motion index		13262±368[b]	12267±209[a]	12534±317[c]
Standing duration (hrs)		12.3±0.1[b]	12.1±0.1[a]	12.1±0.1[c]
Lying duration (hrs)		0.9±0.1	1.1±0.1	2.3±0.1
No. of lying bouts		1.9±0.1[a]	2.0±0.1[a]	1.1±0.1[b]
No. of steps	Night	269±13[a]	264±7[a]	291±14[b]
Motion index		1056±49 [b]	1093±26[a]	1171±55[c]
Standing duration (hrs)		5.4±0.2[b]	4.2±0.1[a]	4.5±0.1[a]
Lying duration (hrs)		5.4±0.2[b]	6.4±0.1[a]	6.2±0.1[a]
No. of lying bouts		4.4±0.2[a]	4.6±0.1[a]	5.2±0.2[b]

[a,b] Means with different superscripts within the same row and time of day are significantly different.

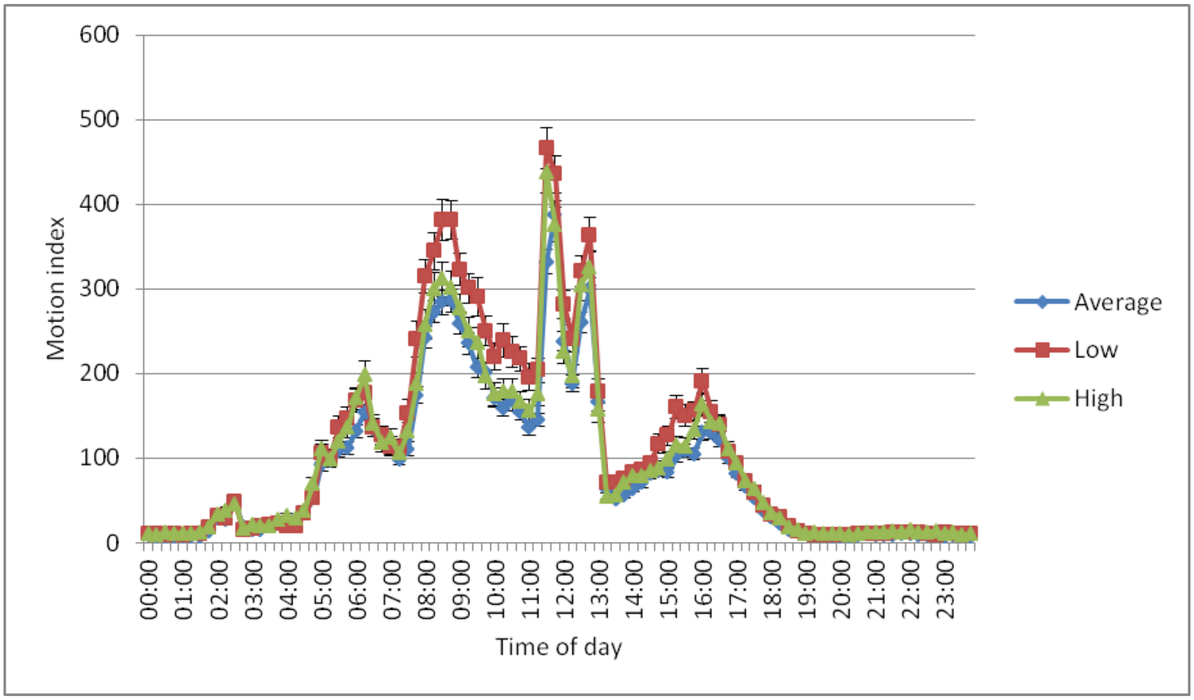

Figure 4.12: Overall daily activity of low, average and high milk producing Holstein cows at Mapanga Farm

The average daily number of steps and motion index were similar between Bunda and Langhill herd cows (Figure 4.13). Mapanga cows had the highest motion index as they walked to and from grazing areas while cows at Bunda College, smallholder farms and in the Langhill herd were fed indoors.

Cows in all the farms spent more time of the day standing than lying, with Mapanga and Langhill cows having the longest and shortest daily standing duration, respectively.

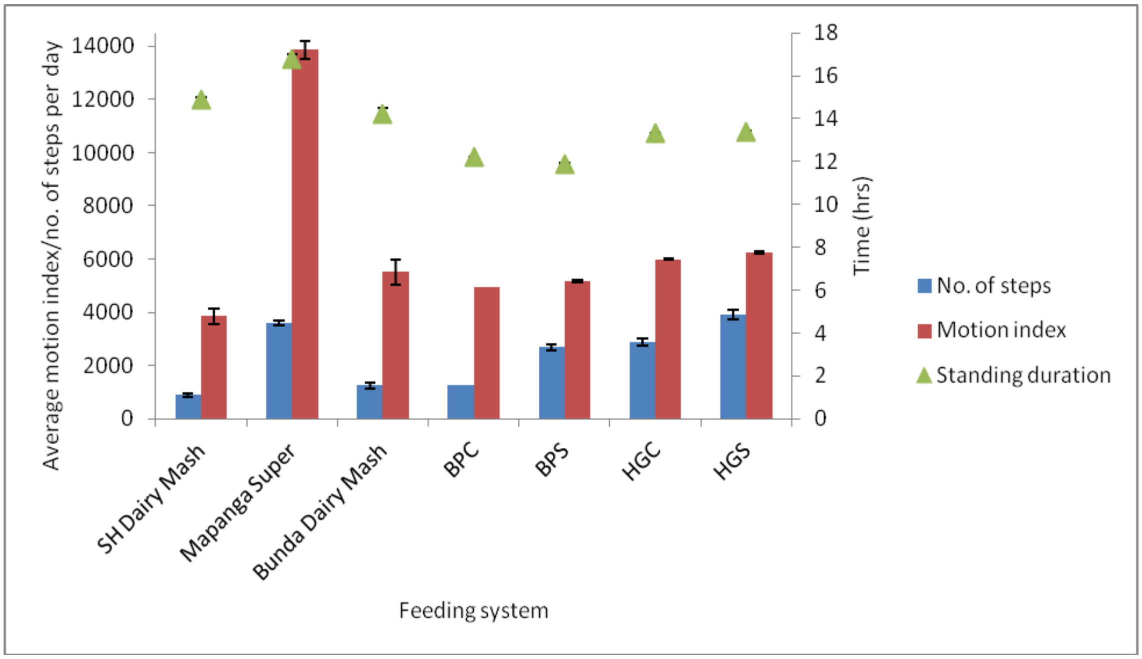

Figure 4.13: Daily activity of cows in Malawi farms and the Langhill Herd in the UK. BPC=by-product control; BPS= by-product select; HGC=home-grown control; HGS=home-grown select; SH =smallholder; error bars=standard error of the mean

4.4 DISCUSSION

4.4.1 Management systems

Distinct management systems were evident in the farms studied and these could be linked to resource availability and productivity of dairy cows. The Langhill herd in the UK is characterised by high management input with strict protocols based on recommended welfare and nutritional requirements as well as a well-established recording system where data could be retrieved as required. Milk production from the Langhill herd was higher than that reported for other Holsteins in Denmark and Ireland (Nielson et al., 2003; Hansen et al., 2006; Walsh et al., 2008) but similar to previous results from the same herd (Pryce et al., 2001; Bell et al., 2007; Pollott & Coffey, 2008) with slight variations that can be attributed to improvement in productivity over time and change in management systems. The differences with other similar systems reflect differences in feeding levels and management environment.

Milk productivity from smallholder farms was also similar and in some cases higher than productivity reported from similar production systems in Malawi and other countries. Chindime (2008) reported daily milk yields for Holstein cows that averaged 14 litres in farms that had access to credit and while Tebug et al. (2012) reported lower average daily yields of about 10 litres. King et al. (2006) reported higher averages of 13 to 18 litres/day that varied depending on the location in Kenya. The yields from Mapanga farm were also similar to those reported by Chagunda et al. (2004) and Ahmed et al. (2007) from similar large scale farms in Malawi and Morocco but lower than those reported in other similar farms in Zimbabwe, Malawi and Cameroon (Makuza & MacDaniel, 1996; Wollny et al., 1998; Ageeb & Hayes, 2000). Differences between and within production systems are expected due to variations in the production environment, management practices and access to resources as demonstrated by Kawonga et al. (2012).

4.4.2 Milk production, energy balance and fertility

4.4.2.1 Langhill herd

Both high and low genetic merit cows had distinct and consistent patterns of milk production and fertility which were related to the feeding systems. The results showed an interaction between genetic merit and feeding system where cows of average genetic merit fed low forage diets with higher CP and ME produced higher milk yields than high genetic merit cows fed high forage diets that had lower CP and ME. These results are similar to earlier findings on the same herd by Pollott & Coffey (2008) and other herds (Nielsen et al., 2003; Horan et al., 2005; Windig et al., 2008) and demonstrate that productivity is a function of both genetic merit and feeding systems. This principle was also apparent in farms in Malawi, where cows that had access to higher quality and quantity of concentrates performed better than other cows. In smallholder farms cows that were fed dairy mash as a concentrate had higher milk yield. Such responses in productivity are related to feeding efficiency which is a ratio of output to intake (Brody, 1945). Apart from feed quality, feed efficiency is also dependent on genotype and physiological state (Blake & Custodio, 1984). The genotype effect is through the genetically determined potential for milk yield as shown by higher milk yields in cows of high genetic merit. The effect of the physiological status is demonstrated through differences in milk yield attributed to the influence of nutrient partitioning depending on stages of lactation.

Fertility was lower in high genetic merit cows and can be attributed to the genetic selection for high milk fat and protein levels in high genetic merit animals which results in nutrient mobilisation biased towards milk production rather than reproductive function (Leroy et al., 2010a).

Cows in all the systems had their DFHLA almost a month earlier than the DFH. It is not clear whether the difference in time between DFHLA and DFH reflects a lack of, or reduced, behavioural heat, persistent corpora lutea, or that oestrus was just not detected early enough. Reduced behavioural heat (Van Eerdenburg, 2006; Dobson et al., 2008) and persistent corpora lutea (Opsomer et al., 2000; Lucy 2001) have been reported in high yielding cows. Dobson et al. (2008) reported a decrease in the duration of standing oestrus and the percentage of cows displaying standing oestrus as well as a reduction in detected oestrus duration from 15 to 5 hours. Lopez et al. (2004) also found that cows producing more than 39 litres of milk per day had a shorter oestrus and lower serum oestradiol concentrations than those producing less than 39 litres per day ten days before the day of oestrus. Increased metabolic clearance of oestradiol in high producing cows is thought to decrease circulating oestradiol (Sangsritavong et al., 2002). Increased circulating oestradiol has been associated with increased oestrous duration (Nebel, 1997). Persistent corpora lutea imply longer luteal phases, inactive ovaries and delayed cyclicity (Lucy 2001; Stevenson, 2001) and hence longer days to observed heat and subsequent service.

Although all the systems described in the current study had similar intervals to first recorded heat and first insemination, they had significantly different intervals to successful service. The high genetic merit cows had the longest interval to successful service and this could be related to failure to support conception while more nutrients were mobilised towards milk production. Lucy (1998) reported lower progesterone production in high genetic merit than average genetic merit Holsteins and this was associated with inability to support pregnancy. The low progesterone was attributed to increased feed intake and a high rate of metabolising progesterone in high producing cows. The other reason for longer interval to successful service in high genetic merit cows could be high incidences of long luteal phases (Opsomer, 1998). Long luteal phases could be due to poor follicular development, reduced oestradiol secretion, increased oestradiol metabolism and the failure of the follicular oestradiol-dependent mechanisms for luteolysis (Lucy, 2001). Another cause for the long intervals to successful insemination could be early embryonic mortality. Sheldon et al. (2006) reported about 22 and 6% embryonic loss in the first 21 days and 21 -42 days after fertilisation, respectively.

Milk yield acceleration was highest in LFS cows, as expected. HFS cows had MYA similar to that of LFC cows although their feeds were different suggesting that HFS cows had to mobilise more nutrients from the body in order to maintain milk yield. This is further supported by the highest body energy loss occurring in HFS cows. The results confirm that high yielding cows have the ability to prioritise nutrients towards milk production and when the diet does not meet the nutritional needs, nutrients are mobilised from body energy reserves (Leroy et al., 2010a). The results further support Hansen et al. (2006) who suggested that higher yielding cows have higher MYA at any point in lactation, which could be related to the physiological stress of milk production. Horan et al. (2005) also reported higher peak milk yield and longer days to peak milk yield in high producing Holsteins on high concentrate feeding systems compared to moderate producing breeds under the same feeding system.

The pattern of nutrient mobilisation between breeds was further illustrated by changes in BCS between calving and service in relation to DFH. Gillund et al.

(2001) reported that BCS loss of ≥1.25 is considered as a marked loss with a negative effect on conception. The results showed that only a few cows, mostly high genetic merit cows under high forage, had a marked BCS loss. The marked BCS loss in these few cows did not seem to have negatively impacted DFH. Cows that neither lost nor gained BCS had higher DFH than cows than cows that lost BCS. This confirms previous reports that body condition score loss before service is important for subsequent reproductive processes (Friggens, 2003). Some high genetic merit cows had increased DFH with BCS gain above 0.75 BCS. The reason for the DFH increase could be due to conversion of nutrients to milk synthesis being a priority in high genetic merit cows as opposed to the reproductive process. Therefore as more energy was available, more energy was partitioned towards milk production than resumption of ovarian activity. Another reason could be body fat storage interfering with reproduction. Leroy et al. (2010b) demonstrated that excess lipid accumulation resulted in significant reduction of embryo quality and alteration of mRNA expression patterns in genes that are important for development.

Cows in their third lactation had the highest body weight and energy content. This was expected as the cows in first and second lactation are still growing and have relatively smaller body size (Taylor et al., 2004).

4.4.2.2 Smallholder farms

Cows in smallholder farms that supplemented feed with dairy mash had higher milk yield than those feeding maize bran in both the baseline survey and the monitoring study. In the monitoring study there were wide variations in the milk yield even within farms that used either maize bran or dairy mash. This could be due to variations in the amounts of concentrate given. Njarui et al. (2011) reported similar results for smallholder dairy farmers in Kenya where some dairy cows were fed constantly low amounts of concentrate of about 2kg per day throughout the lactation period. The practice could be due to lack of understanding of dairy cow feed requirements which is further constrained by the inconsistent availability and cost of the feed ingredients. Farmers feeding constantly low amounts of concentrates throughout the lactation period may not fully exploit the production potential of the cows. Kaitho et al. (2001) demonstrated that dairy cows yielded more milk when fed 8kg of concentrates per day only for the first 12 weeks of lactation as opposed to constant feeding of 2kg per day throughout lactation. The study demonstrated that feeding of concentrates could be stopped after the first 12 weeks without an adverse effect on milk yield. Further training of farmers, awareness campaigns coupled with monitoring and evaluation of cow productivity are required in order to improve dairy production. The monitoring and evaluation ought to provide feedback to the farmers relating management practices to income from the animals.

Farmers often decided on the type of concentrate to use depending on affordability at the time and showed a lack of feeding plan. There is need to further work with farmers to develop medium to long term cow feeding budgets so that appropriate feeding regimens are maintained. While farmers seemed to be aware of the importance of feeding dairy mash, it also seemed they had a perception that maize bran was a direct alternative to dairy mash. It is important that this study was able to demonstrate the differences in milk yield and fertility. It may also be important to further demonstrate the importance of budgeting and consistent feeding of adequate amounts in relation to productivity (milk yield and fertility) and subsequently increase income. This could also be demonstrated in terms of the link between animal welfare and productivity as evident from the Langhill herd.

Apart from the energy supplements, the cows were fed with crop residues and forages. Groundnut haulms served to supplement protein in the diet of the cows although the protein levels are lower than that of other legumes promoted for dairy production such as Lucerne (*Medicago sativa*) and centrosema (*Centrosema pubescens*). Chingala et al., (2013) reported crude protein levels of 13, 21 and 25% in groundnut haulms, Lucerne and centrosema hay, respectively. These results show that there is further need to improve the quality of feeds for dairy cows under smallholder farming.

The results confirm the importance of feeding management on milk yield which can also be translated into income. Land O'Lakes (2012) reported a 25% increase in milk yield and gross profit margins of 50 – 60% for farmers feeding dairy mash to cows. Kumwenda & Msiska (2008) also demonstrated higher gross margins from dairy cows fed maize bran mixed with cottonseed cake than maize bran alone.

Milk protein levels were lower than values reported by Chingala et al. (2012). These results could reflect generally low amounts of concentrates in the diet. Robinson and MacQueen (1997) demonstrated an increase in milk protein that could be associated with increase in the proportion of concentrates. The increase in the proportion of protein was associated with increase in digestible nutrients and flow of bacterial protein from the rumen to the small intestines. However, the increase had a threshold at which protein percentage started declining as a result of suppressed bacterial growth with a decrease in pH in the rumen.

In terms of fertility, farms using dairy mash had a significantly higher calving interval than those using maize bran (Table 4.5). However, there were only 8 farms where calving interval was reported in farms using dairy mash compared to only 3 farms reporting calving interval for farms using maize bran. Having only a few farms from which calving interval could be determined may be an indication of long calving intervals such that farmers (who mostly rely on memory) were not able to recall actual calving dates. The results could also mean that there are other factors affecting calving interval other than the type of concentrate used. Generally the calving intervals and number of days from calving to service indicate poor fertility as they are longer than the optimal figures of 390-420 and less than 90 days, respectively for smallholder farms (Perreira, 1999). The wide variation in the variables gives an indication that some farms are within optimum production ranges while other farms were extremely poor.

The general trend was that the fertility traits are better with better type of concentrate, housing and feeding management. However, the duration of these traits was longer than the ranges for optimal production. For example the DFS were all above the optimal of less than 90 days recommended for smallholder farms (Perreira, 1999). Given the lowest DFS of 92 days, coupled with high chances of repeat inseminations, longer calving intervals seem inevitable. The results show that the current dairy management systems are not good enough for optimal production and need further improvement. Otherwise the current productivity translates to lower lifetime productivity in terms of potential milk yield and number of calves born.

An interaction between housing, feeding management and type of concentrate used made it difficult to fully explain the differences observed in DFOH and DFS. The results may indicate more accuracy in heat detection in farms with better hygiene. It is probable that in farms with low hygiene, farmers spend less time in the pens, which translates to less time to observe animals leading to misidentification of heat or late heat detection for an insemination to be done. This could be attributed to the fact that, as farmers with better hygiene care for the housing they have an opportunity to spend more time observing the animals and hence timely heat detection and seeking AI services.

4.4.2.3 Mapanga Farm

There was no feeding intervention to boost productivity of low producing animals at Mapanga Dairy Farm. However, feed concentrate levels were quite high, particularly for high producing cows. Generally the practice is that the first 10 litres is maintained on forage, and then a kilogram of concentrate is added for each 2 litres of milk thereafter. Other farms provide outright 1 kg concentrate for each 2 litres of milk produced (Moran, 2005). Going by the latter option, it means cows in high, moderate and low yielding cows would be fed about 8.5, 6 and 4 kg of concentrate per day. Moran (2005) further recommended that the maximum concentrate intake should be 50 % of dry matter intake and that the feeding should be based on weight, milk yield, fat content and quality of forages available. While fat content and quality of forages may be difficult to analyse on farm, weight and milk yield can easily be monitored and recorded. Estimates of fat content and forage quality could be made based on literature and prevailing environment on the farm.

The current feeding plan used on the farm was only based on milk yield with no justification that could be linked to maintenance and milk production requirements. Studies have shown that an increase in concentrates increases milk protein up to a certain threshold beyond which it has a negative effect on milk yield as rumen microbial populations are negatively affected by high acid production resulting from increased concentrates in the diet (Robinson & MacQueen, 1997). It is possible that the high concentrate feeding at the farm may have had a negative effect on milk yield. This could be further supported by high body condition scores suggesting that more nutrients were being stored than mobilised towards milk production. However, this needs further analysis in relation to the quality and quantity of forage and other supplements available to the animals along with the overall feed intake.

Meanwhile, it is suggested that the feeding plan at Mapanga dairy Farm needs to consider taking into account the live weights of the cows in addition to milk yield. This may be possible for this particular farm as there is a weigh bridge available at the farm. Milk and forage quality could be estimated in consultation with experts and based on this information appropriate concentrate feeding levels could be determined to meet daily feed requirement of the cows and optimise cow productivity.

Analysis of data on milk yield based on whether the cows were consistently in one feeding group or moved between feeding groups during the study period showed no significant difference in milk yield. This may have been due to the wide variations within groups as each group comprised both high and low yielding cows. Data for high and low yielding cows could not be analysed separately due to the small numbers of cows involved. Cows that changed feeding groups had declining milk yield but accumulated nutrients in their body reserves translating to high BCS. High BCS (greater than 3.0) are reported to be negatively associated with milk yield and fertility (Roche et al., 2009).

Age at first service was 1.6±0.3 years while age at first calving was 2.4±0.3 years. These ages are similar to other studies done on similar farms and are higher than the recommended age according to Heinrichs (1993) who recommended the average age at first calving in Holsteins to be ≤ 24 months. The calving interval at Mapanga Farm was long with wide variation suggesting a challenge with breeding management either to do with heat detection, service or long postpartum anoestrus. With natural service being most common, the most likely problem may have been related to heat detection as cows on heat only grazed with bulls for 2 days. It is likely that cows on heat were spotted late. The other challenge was management of the 60 day VWP. It was possible for cows to be left longer than 60 days as there was no systematic method to track cows that were within or beyond the VWP. Records also showed that some cows were served before the VWP elapsed with cows served as early as 26 days postpartum. A VWP of 45 to 60 days post-partum is recommended and this period allows for complete uterine involution and resumption of ovarian cyclicity in order to improve chances of successful conception following an insemination (Fetrow et al., 2007). Inchaisri et al. (2010) showed that extending the VWP may be beneficial in some cases but for Mapanga Farm, the reduction and extension of the VWP was not planned but largely due to lack of record tracking.

During the monitoring study, two major challenges were observed with regard to heat detection and insemination of animals. The first challenge was to do with the number of cows and absence of a breeding plan. It was difficult to track cows to be served as the duty to identify cows ready for service solely rested on herdsmen who had no idea on whether cows were still in the VWP or not. Secondly, there was lack of proper record tracking which was further made difficult without a computer for record keeping. Data saved in a computer could easily be organised and analysed to isolate cows due for service and alert the herdsmen to such cows. The current system results in serving animals by chance and mostly those showing heat and seen by herdsmen. Potentially some cows on heat are easily missed thereby prolonging days to service and calving interval which is undesirable.

High producing cows had significantly more days to service than the other groups. Similarly the high producing cows had the most days from calving to the time data monitoring ended. This could be related to high milk yield being associated with delayed resumption of oestrous activity (Robinson et al., 2006) as discussed above. The cows may have been struggling to meet requirements for milk production and hence return to ovarian cyclicity was delayed. However, the number of cows that were served in the study was too small and this hypothesis needs further investigation with more cows from similar production systems.

4.4.3 Cow Activity

Monitoring cow activity using accelerometers was initially meant to assist in oestrus detection. However, the results from Malawi farms did not show any trend that could be associated with oestrous behaviour. Although accelerometers have been successfully used elsewhere for heat detection (Firk et al., 2002; Lovendahl & Chagunda, 2010), the current results suggest that cow activity under smallholder farms and Mapanga was confounded by other factors such as pen hygiene that made it difficult to relate activity to heat behaviour. There was more cow activity in farms with pens under poor hygiene conditions and this could be attributed to more tail swishing and feet stomping in response to the presence of flies in pens less frequently cleared of dung. The discomfort created could also have resulted in the cow frequent movement while seeking a more comfortable place. Besides the hygiene, data recording of the accelerometers was also not consistent as no data were recorded on some days.

Results from Bunda Farm also suggest differences in activity in relation to genotype with Holstein-Malawi Zebu crosses being more active than Holstein cows, which could be related to the temperament of the cows. Holstein cows with access to lower energy concentrates at Bunda were less active, but it was not clear if the lower activity was just related to quality of the concentrate or if there were other factors as cows from smallholder farms with similar concentrates had higher activity. Although cows accessing low quality diets should eat more, if the feed is less palatable and cold water is not freely available they may not eat more (Kellems, 2000; Barber et al., 2010). Further, Ranjhan (1999) reported that up to 60 % of dry matter intake of dairy cows in the tropics is from crop residues. Cows on such feeding practices exhibit low voluntary intake of about 1.5% of body weight due to the bulkiness of the digesta in the reticulorumen as well as a slow rate of digestion.

Generally all cows spent more hours of the day standing than lying. The results are similar to findings in the UK where cows housed in straw courts spent about 16 hours per day standing but different from cows housed in cubicles that spent about 11 hours standing (Langford et al., 2013). The study in the UK demonstrated that cows rearranged their resting and feeding time depending on how housing environment provided comfortable environment for lying. Cows housed in straw courts lay down at night and fed during the day while those that were housed in cubicles fed at night and lay down during the day when they had access to the grazing field.

The results also showed an association between production system, energy balance and cow activity. HGS were the most active while BPC cows were least active. This could be associated with the quality of the feeds in the systems and the genetic merit of the cows. HG feeds were less dense in terms of metabolisable energy and crude protein than BP feeds. Hence high genetic merit cows on HG spent more time standing and feeding to increase feed intake to match with their high milk production while average genetic merit cows on BP feeds were less active as their feed quality was better and milk production relatively lower.

Cows in negative energy balance were less active. However, there was no significant difference in time spent standing and lying. There is need for further analysis to investigate more details on cow activity in terms of time budgets such as feeding bouts and their durations. Individual cow behaviours may also have to be taken into account as wide variations between some individuals within production systems were evident through high coefficients of variation in the dataset.

4.5 CONCLUSION

Genetic merit, feeding system, milk yield and energy balance influence dairy cow fertility in different production systems under study. The study confirmed that high genetic merit cows have longer intervals between parturition and successful insemination and that they mobilise more nutrients towards milk production than average genetic merit cows. Milk production from average genetic merit cows fed higher feed quality is higher than that of high genetic merit cows on a relatively lower quality feed.

Daily milk production in Malawi was less than half the quantities produced in the UK. The average total 305 day milk production per cow in Malawi was 3752 and 4362 litres at Mapanga Farm and in smallholder farms, respectively while it was 8967 litres in the UK. However, there were wide variations in production levels in Malawian herds suggesting that there are opportunities to improve milk production with appropriate management practices. Production in Malawi also showed inconsistent lactation and body energy content patterns which could be linked to variations in feed quality and quantity. There is need for improvement in feed quality and quantities supplied based on nutritional requirements of the animals.

Fertility traits in Malawi herds showed longer intervals from calving to first high luteal activity and service than the UK herd and this was associated with inadequate feeding practises. The high variation in these traits suggests that the traits can be improved following appropriated management, record keeping and utilisation.

Cow activity could not be associated with oestrous behaviour in Malawi due to confounding factors of feeding and housing management. All feeding systems in Malawi and the UK showed that that energy availability in the feed could be associated with cow activity. Cows on a feeding system with lower ME and CP were more active than those on a feeding system with higher ME and CP. Cows in NEB were less active and produced more milk than those in positive energy balance. However, there is need for further detailed analysis on cow time budgets in relation to energy balance, feeding behaviour and activity. In addition, data from Malawi showed that restlessness associated with poor hygiene could also be associated with activity measured by accelerometers.

CHAPTER 5: PREDICTION OF PREGNANCY IN DAIRY CATTLE UNDER DIFFERENT PRODUCTION SYSTEMS

5.1 INTRODUCTION

Achieving pregnancy in dairy production is the major indicator of reproductive efficiency. Reproductive efficiency is the ability of a farm to quickly breed cows after calving with a minimum number of inseminations per cow (Varner et al., 2009). The challenge is to achieve the pregnancies in a timely and cost effective manner as both timeliness and cost affect profitability through influence on milk production, lifetime productivity of cows as well as herd expansion and/or availability of replacement stock. Unfortunately, reproductive efficiency has greatly been affected by declining fertility over the last three decades (Leroy et al., 2009). Declining fertility is evidenced by decreased oestrus detection rates, conception rates, and an increased number of services per conception (Walsh et al., 2008) among other factors. The impact of declining fertility increases the cost of production due to increased repeat breeding, prolonged post-partum anoestrus and increased involuntary culling due to reproductive reasons (Berglund et al., 2008; Bell et al., 2010; Chiumia et al., 2012).

Many studies have provided an understanding of the biological factors underlying declining fertility which is a baseline from which the challenge to achieving reproductive efficiency can be addressed. It is established that declining fertility is particularly a challenge in high yielding cows due to genetic merit and nutritional management that are optimised towards lactation (Leroy et al., 2009). Cows tend to prioritise nutrient mobilisation towards milk production over fertility in early lactation (Lucy, 2003; Leroy et al., 2010a) and this prioritisation of nutrients towards milk production also goes beyond the early lactation in high yielding cows (Leroy et al., 2010a). The prioritisation is genetically influenced thereby resulting in the body concentrating on milk production rather than the restoration of ovarian function and subsequent conception. Lopez-Gatius (2003) and Wiltbank et al., (2002) also reported an increase in ovarian dysfunction along with increase in milk yield in high yielding cows which may also be linked to nutrient prioritisation towards milk production. The ovarian dysfunctions include follicular anovulation, ovarian cysts, sub-oestrus and sub-luteal function and these were more directly associated with prolonged postpartum anoestrus than milk yield (Yaniz et al., 2008; Garcia-Ispierto et al., 2012).

Apart from the underlying biological factors, studies also show the relationship that exists between declining fertility and other dairy production factors (McDougall, 2006; Bello et al., 2012; Mee, 2012). Several production factors have been demonstrated to affect fertility and among the principal factors is nutrition (Webb et al., 2004; Robinson et al., 2006; Ashworth et al., 2009). Nutrition affects many other factors that are also associated with fertility such as body condition scores (Roche et al., 2009), milk yield and composition (Friggens et al., 2007) metabolites and hormones (McDougall et al., 2005). Work reported in Chapter 4 (Table 4.8) also showed that there were differences in fertility traits that could be attributed to genetic merit and feeding system. Both the biological factors and the association of fertility with other production factors provide an opportunity to develop a tool to predict insemination outcomes given particular information. Inchaisiri et al., (2010) demonstrated that milk yield, time of insemination, breed, parity, season, interval from calving to insemination, and time to peak milk yield influenced successful first insemination in Dutch dairy cows from various herds. This study built on this approach, by developing and validating a pregnancy prediction model using data from cows managed under controlled experimental conditions over a period of seven years.

5.2 MATERIALS AND METHODS

The work was undertaken with cows from the Langhill pedigree herd on high and low forage feeding systems described in chapter 3. Data were also retrieved from the Langhill database using the SQL Server Management Studio 2008, cleaned in Microsoft Excel 2007 and exported to SAS 9.3 for analysis as explained in chapter 4.

5.2.1 Traits Retrieved and Calculated

A total of 1267 records were retrieved from 566 cows between their first and fourth lactation that calved between September 2003 and December 2010. Records with missing variables and extreme values were removed and a total of 860 records from 455 cows were used for analysis. Extreme values were identified through the proc univariate procedure of SAS 9.3. Traits included animal identification, date of birth, genetic group, feeding system, lactation number, calving date, weight and body condition score (BCS); first and last service dates, total number of services, last service weight, BCS and milk yield as well as pregnancy diagnosis results. Body energy content (BEC) at calving and service, milk yield acceleration (MYA), days to first heat and successful service were calculated. BEC and MYA were calculated explained in chapter 4.

5.2.2 Data Analysis

Cows included in the analysis were those that became pregnant with 1 to 7 inseminations and excluded cows that did not become pregnant at all. Cows were grouped according to the number of inseminations to achieve pregnancy.

The groups were pregnancy with 1, 2, 3 and >3 inseminations. The groups had 326, 198, 136, and 200 cow-lactations, respectively. Analysis of variance and chi-square statistics were used to determine factors that influence the number of inseminations per pregnancy. Thereafter outcome of the first insemination and that of the first three inseminations was modelled using a logistic regression model. Initially random intercept models were built to take into account within cow correlation as some cows appeared in several lactations. The output from the GLIMMIX procedure of SAS 9.3 with logit link showed that the variance of the random effect (σ^2_r) was 0.261±0.175. Based on the variance the estimated pseudo intraclass correlation coefficient (ICC) was 0.079. The ICC was calculated using the Snijders-Bosker formula (Sun et al., 2011):

$$ICC=\sigma^2_r /(\sigma^2_r +3.29) \qquad (5.6)$$

The ICC was used to estimate the variance inflation factor (VIF). VIF indicates the relative increase in variance caused by ICC. VIF was estimated as 1.069 from the formula:

$$VIF=1+ (m\text{-}1)\ ICC = 1+(1.89-1)0.079 = 1.069 \qquad (5.7)$$

Where *m* is the average number of appearances per cow in the dataset.

The small ICC and VIF suggested that the random intercepts model may not be necessary (Sun et al., 2011) and hence a stepwise logistic regression using the LOGISTIC procedure of SAS 9.3 was applied in the development of the final model.

The data were also checked for multicollinearity by running a correlation analysis and multicollinearity diagnostics using the CORR and REG procedures of SAS 9.3, respectively. Field & Miles (2010) reported that multicollinearity exists when there are strong correlations of 0.80 and above between predictor variables. There was no strong correlation between predictor factors and the highest correlation was 0.41 that was between calving BEC and the percentage change in BEC between calving and service. However, multicollinearity diagnostics showed some evidence of multicollinearity when both calving BEC and the percentage change in BEC between calving and service were included in the same model. The tolerance factors for calving BEC, service BEC and percentage change in BEC between calving and service were 0.27, 0.29 and 0.38, respectively, which is below 0.40 which Allison (2012) recommended as a level below which multicollinearity should be a concern. Removing calving BEC from the model resulted in tolerance factors for all predictor variables ranging from 0.66 to 0.97 while removing percentage change in BEC between calving and service had tolerance factors ranging from 0.58 to 0.96. Hence model development was undertaken in such a way that both calving BEC and percentage change in BEC between calving and service were not included in the same model.

The predictor factors used for model development were genetic merit, feeding system, lactation number, calving ease, occurrence of disease prior to first insemination, interval from calving to first heat, milk yield at service, calving and service BEC as well as interval from calving to nadir body energy content and percentage change in BEC between calving and service. Interactions between genetic merit, lactation number and feeding systems were also taken into account. Milk yield acceleration and interval from calving to highest milk yield acceleration were also included. However, not all cows in the original dataset had these latter two variables as some cows had missing information on initial milk yield. Hence modelling for these used a subset of the dataset which had 473 records from 320 cows.

Modelling was done for both pregnancy to first insemination and pregnancy to the first three inseminations. The model for pregnancy to first insemination used the binary response pregnancy diagnosis results (PDR) that was assigned a value of one if a cow was pregnant with the first insemination and zero if the pregnancy occurred with two or more inseminations while the model for pregnancy to first three inseminations had PDR as one if the cow was pregnant with the first three inseminations and zero if the pregnancy occurred after more than three inseminations. Pregnant cows were defined as those that were confirmed pregnant through rectal ultrasound along with a recorded subsequent birth at 282±14 days from the last date of recorded service.

Model selection

A stepwise logistic regression was used where predictors were entered into and removed from the model in such a way that each forward selection step could be followed by one or more backward elimination steps. The stepwise selection process terminated where no further effect could be added to the model or if the current model was identical to a previously visited model. The final models were selected based on overall significance of the model and individual predictors. The overall model significance was selected based on the -2Log Likelihood with a chi-square test with $p<0.05$. Individual predictors were assed using the Wald chi-square statistics and predictors with $p<.0.05$ were selected as this showed that the predictors were making significant contribution to the PDR outcome. Further odds ratio estimates of the predictors along with their 95% confidence intervals were considered. The odds ratio estimates whose confidence interval did not overlap 1 were considered significant.

To further test the quality of the model, a Hosmer-Lemeshow goodness of fit test was conducted. The selected models had $p>0.05$ which indicated that model had a good fit to the data according to Guido et al. (2006).

5.2.3 Model validation

Model validation was undertaken using data from 154 cows from the same herd that were not included in model derivation. These were cows that calved between January and May 2012 and were served by September 2011 before the feeding system was changed to home grown and by-products feedings systems described in chapter 3.

Further validation was undertaken using a dataset comprising 105 cows that calved between January and May 2012 and from a different herd (Acrehead herd) comprising the same breeds (select and control) but under a different feeding system from the same farm. The cows were commercially managed but available for research purposes. The cows were housed in two groups by stage of lactation and were fed a TMR which was formulated to meet either maintenance+35 litres of milk per day or maintenance+ 20 litres of milk per day. Cows in the early lactation group yielding over 35 litres of milk per day were also fed additional concentrate in the parlour. The rations were formulated using SAC Feedbyte rationing programme. The TMR consisted of maize silage, grass silage and a concentrate blend which included cereals, distillery by-products and soya. The proportion of individual ingredients in the blend altered over time depending on availability and price (Roberts 2014, personal communication). The dataset was used to validate model 1 described below which used data on genetic merit, lactation number, DFH milk yield at service and BEC.

Sensitivity analysis, the area under the curve (AUC) of the receiver operating characteristic (ROC) curve and the Hosmer and Lemeshow goodness of fit test of the logistic procedure of SAS 9.3 were applied on the validation data set. Cows from the validation data set were assigned predicted probabilities of pregnancy with the first insemination or the first three inseminations based on the respective predictive model developed. The predicted probabilities were compared to the actual pregnancies where a probability of 0.55 and 0.80 were selected as a cut off for pregnancy with the first and the first three inseminations, respectively. The cut off points were selected based on the points where the sensitivity and specificity of the models were closest to each other (Allison, 2012).

5.3 RESULTS

5.3.1 Cow characteristics and number of inseminations per pregnancy

Cows that became pregnant with first, second, third and more than three inseminations represented 38, 23, 16, and 23% of the population, respectively (Table 5.1). A point to note here is that only cows that ultimately became pregnant are included in Table 5.1 i.e. cows that never become pregnant were excluded from the analysis. The distribution of the cows in the insemination groups was not significantly different between the production systems.

Table 5.1: Distribution of Holstein cows that became pregnant with different numbers of inseminations within feeding and genetic groups at SRUC Dairy Research Centre

Number of inseminations	n	Frequency (%) within groups				
		*HFC (263)	HFS (190)	LFC (207)	LFS (200)	Total cows
1	326	36	34	43	40	38
2	198	26	25	19	22	23
3	136	18	16	18	11	16
>3	200	20	26	20	27	23
Total	860	31	22	24	23	100

*HFC = high forage control; HFS = high forage select; LFC = low forage control; LFS = low forage select. The figures in parenthesis show the number of cows in each production system

The proportion of cows that became pregnant with the first insemination were significantly higher ($p<0.05$) than that of cows getting pregnant with the second, third and more than 3 inseminations. The median for the number of inseminations per pregnancy was 2 resulting in 61% of the pregnancies. The first three inseminations resulted in 77% of the pregnancies. Overall, there were more cows (39%) that were in their first lactation than those in their second (29%), third and fourth lactations (32%). The results generally showed that the dairy herd had more cows in their first lactation than those in higher lactation numbers which may be reflecting involuntary culling throughout lactations as well as voluntary culling (transfers) that were made after the third lactation. The distribution of the lactation numbers was not significantly different between the production systems.

First lactation cows had a significantly higher proportion of cows (41%) that became pregnant with first insemination than those in their third and fourth lactations (33%, Table 5.2). However, this was not significantly different from the proportion of cows in their second lactation.

Table 5.2: Distribution of Holstein-Friesian cows that became pregnant with different numbers of inseminations within lactation number at SRUC Dairy Research Centre

Number of inseminations	n	Frequency (%) within lactation number			
		1 (336)*	2 (254)	3 (273)	Total cows
1	326	41	39	33	38
2	198	24	18	26	23
3	136	14	19	15	16
>3	200	21	24	26	23
Total	860	39	29	32	100

*The figures in parenthesis show the number of cows in each lactation

Table 5.3 below shows significant differences ($p<0.05$) in some characteristics of the cows that became pregnant with the first, second, third or more inseminations. Cows that became pregnant after more than three inseminations had significantly higher calving and service weight, body energy content and service condition score. They also had significantly lower milk yield at service, BCS and BEC loss between calving and successful service. However, the DFH, DFS, days to nadir energy balance and milk yield acceleration were not significantly different between the insemination groups.

The DSS and calving intervals were significantly different between all the insemination groups. Cows that became pregnant with more than three inseminations had the highest DSS and calving interval.

Some of the reproductive characteristics of the cows also differed with the lactation numbers of the cows. There were significant differences on body weight and energy content at calving and service as well as milk yield at service ($p<0.05$). All these variables were significantly highest in cows in their third or more lactation ($p<0.05$), followed by those in their second and first lactation, respectively. This was expected as the cows in first and second lactation were still growing and hence they had to partition nutrients such that growth was accommodated. There was no significant difference in the number of days to first recorded heat as well as first and last service between lactations suggesting that these variables were not affected by lactation number.

Table 5.3: Reproductive characteristics of Holstein cows that became pregnant with different numbers of inseminations at SRUC Dairy Research Centre

Variable	Number of inseminations per pregnancy (least square mean±SEM)			
	1 (326)	2 (198)	3 (136)	>3 (200)
Calving weight (kg)	588 ± 4^{a}	592 ± 6^{ab}	593 ± 7^{ac}	609 ± 5^{b}
Service weight* (kg)	572 ± 4^{a}	586 ± 5^{a}	587 ± 6^{a}	618 ± 4^{b}
Calving BCS	2.3±0.02	2.3±0.02	2.3 ±0.03	2.3±0.02
Service BCS*	2.1 ± 0.02^{a}	2.1 ± 0.03^{a}	2.1 ± 0.03^{a}	2.2 ± 0.03^{b}
BCS change	-0.27 ± 0.02^{a}	-0.22 ± 0.03^{ab}	-0.22 ± 0.03^{ab}	-0.13 ± 0.03^{b}
Calving BEC (MJ)	4657±46	4628±59	4658±71	4814±59
Service BEC (MJ)	4189 ± 43^{a}	4304 ± 56^{a}	4292 ± 67^{a}	4722 ± 56^{b}
BEC change	-9.0 ± 0.9^{a}	-5.7 ± 1.1^{a}	-5.9 ± 1.4^{a}	-0.6 ± 1.1^{b}
DFH (days)	65±2	63±2	63±3	63±2
Days to first service	73±1	70±2	70±2	70±2
Days to last service	74 ± 2^{a}	107 ± 2^{b}	140 ± 3^{c}	183 ± 3^{d}
CI (days)	354 ± 2^{a}	386 ± 3^{b}	420 ± 3^{c}	470 ± 3^{d}
Service MY (litres)	33.2 ± 0.5^{a}	32.4 ± 0.6^{ab}	30.6 ± 0.7^{bc}	29.8 ± 0.6^{c}
Days to PMY	59 ± 2^{ab}	66 ± 3^{b}	56 ± 3^{a}	64 ± 3^{b}
MYA (litres/day/day)	0.56±0.04	0.58±0.06	0.61±0.10	0.45±0.04
Days to nadir BEC	81±4	91±6	77±7	85±6

$^{a, b, c, d}$Means with different superscript within a row are significantly different ($p<0.05$); BCS= body condition score; BEC= body energy content; DFH= days to first recorded heat; CI=calving interval; MY= milk yield; MYA= milk yield acceleration. The figures in parenthesis show the number of cows in per insemination; *Weight and BCS at successful service

Calving ease for the calving before insemination was not significantly different between the insemination groups. Overall, 80 % of the herd had normal births while 17, 2 and 1% had farm assisted births, abortions and vet assisted births, respectively. There was also no significant difference in the occurrence of diseases related to reproduction, feet and udder health prior to first insemination of the cows. The proportion of cows that had reproductive, feet and udder health related diseases prior to first insemination were 9, 9 and 5%, respectively. Calving ease and occurrence of disease also did not differ between genetic merit, feeding systems and insemination groups.

5.3.2 Pregnancy prediction

Pregnancy prediction results differed when the pregnancy was modelled for the first insemination only and the first three inseminations.

5.3.2.1 Pregnancy to first insemination

Table 5.4 shows the results of the random effects modelling for all lactations for the first insemination among cows that ultimately became pregnant. The predictor levels with the lowest odds of pregnancy were used as reference. There was an interaction between genetic merit and feeding system and these were combined to form a variable called production system. The production system, lactation number, calving ease, milk yield acceleration to peak milk yield, number of days to peak milk yield acceleration, body energy content and milk yield at service had significant effect on the outcome of the first insemination ($p<0.05$). Days to first observed oestrus and body energy content at calving and change in body energy content between calving and service were not significant predictors of the first insemination outcome.

Table 5.4: Estimates from a random intercept logistic regression model for predictors of pregnancy to first insemination[†] for Holstein cows at SRUC Dairy Research Centre

Predictor	P value	Predictor levels	Odds ratios	95% Confidence Limits
Production system	0.0029	LFC*	2.19	1.38 – 3.45
Ref: HFS		HFC	1.138	0.89 – 2.13
		LFS	1.17	0.71 – 1.93
Lactation number	0.0321	1	4.31	1.45 – 12.84
Ref: lactation 3		2	2.21	1.10 - 4.41
Calving ease	0.0027	normal	1.51	1.10 - 4.40
Ref: Assisted calving		aborted	5.71	2.10 – 15.6
Body energy content at service (MJ)	0.0006	<3809	4.96	2.32 – 10.58
Ref: >4788		3809 - 4288	2.27	1.27 - 4.06
		4289 - 4788	1.72	1.09 - 2.73
Service milk yield (litres)	<0.0001	25.8 - <31.3	1.61	1.00 – 2.57
Ref: <25.8		31.3 – 37.3	2.4	1.46 – 3.94
		>37.3	4.64	2.59 – 8.23
Milk yield acceleration to peak yield (litres/day^{-2})	<0.0001	0.18 - 0.34	1.31	0.86 - 2.01
Ref: <0.18		0.35 – 0.68	1.32	0.84 – 2.08
		>0.68	3.06	1.86 – 5.02
Days to peak milk yield acceleration	0.0027	6 - 7	0.90	0.59 – 1.38
Ref: <6 days		8-11	1.27	0.78 – 2.07
		>11	2.074	1.23 – 3.51

*HFC=high forage control; HFS=high forage select; LFC=low forage control; LFS=low forage select; Ref=reference; [†]Note that the model was derived using data that excluded cows that never became pregnant

Average genetic merit cows under low forage (LFC) were two times more likely to become pregnant with the first insemination than high genetic merit cows under high forage. There was no significant difference in the likelihood of pregnancy for HFC, LFS and HFS cows. First lactation cows had the highest likelihood of pregnancy with the first insemination followed by second lactation cows. The likelihood of pregnancy for first and second lactation cows were four and two times that of the third or more lactation cows, respectively. Calving ease was a significant predictor of pregnancy with the first insemination. Cows that had assisted calving were less likely to become pregnant with the first insemination than cows that aborted or had normal calving. Cows that had aborted had the highest likelihood (about 6 times) of getting in calf than cows with assisted calving. Normal calving cows had about two times chance of getting back in calf with the first insemination than cows with assisted calving. However, calving ease was eventually dropped from the model taking into account that only a small proportion of the cows (2%) had abortions and that the cause of the abortions was unknown.

Service BEC was also an important predictor of the likelihood of cows becoming pregnant with the first insemination. High BEC (greater than 4788 MJ) resulted in a lower chance of getting back in calf with the first insemination. Cows with BEC of less than 3809 MJ had about 5 times the likelihood of becoming pregnant for cows with BEC greater than 4788 MJ while cows with BEC between 3809 and 4788 MJ had 2 times the likelihood of becoming pregnant for the cows with BEC greater than 4788 MJ.

Some milk yield traits were also significant predictors ($p<0.01$) of the likelihood of becoming pregnant with the first insemination. The traits were milk yield at service, MYA and the interval from calving to peak milk yield acceleration. Cows with high milk yield at service (greater than 37 litres per day) had the highest chance of getting pregnant than those that had lower milk yield (less than 26 litres per day). A lower MYA (less than 0.18 litres/day/day) was associated with less likelihood of getting back in calf than MYA between 0.18 and 0.68 and MYA above 0.68 litres/day/day. Cows with a milk yield acceleration above 0.68 litres/day/day had about three times the chance of getting pregnant than cow with MYA less than 0.18 litres/day/day. The interval from calving to peak MYA showed that cows with an interval shorter than 11 days were less likely to become pregnant with the first insemination. Cows that had longer days to peak acceleration (more than 11 days from calving) had about 2 times chance of achieving pregnancy with the first insemination than cows that cows that reached peak milk yield acceleration in less than 6 days from calving.

Results from a logistic model (used in model 1 below) showed that genetic merit, lactation number, DFH, body energy content at calving, milk yield and body energy content at service were significant predictors of pregnancy to first insemination ($p<0.05$) with no interaction among factors. However, modelling in the subset dataset to include milk yield acceleration and days to peak milk yield acceleration as predictors for pregnancy to first insemination showed that only genetic merit, lactation number, peak milk yield acceleration, milk yield and body energy content at service were the significant predictors ($p<0.05$) of pregnancy to first insemination (Table 5.5)

Table 5.5: Estimates from a logistic regression model for predictors of pregnancy to the first insemination† in Holstein cows at SRUC Dairy Research Centre

Predictor	Reference	Predictor level	Estimate±SE*	Odds ratios	95% Confidence Limits	
					Lower	Upper
Intercept		-	-2.73±0.46	-	-	-
Genetic merit	High	Average	0.43±0.21	1.54	1.01	2.34
Lactation number	3	1	0.76±0.29	2.14	1.21	3.79
	3	2	0.43±0.26	1.53	0.92	2.55
Milk yield at service (litres)	<25.8	25.8 – 31.2	0.62±0.31	1.87	1.02	3.42
	<25.8	31.3 – 37.3	0.98±0.31	2.68	1.45	4.94
	<25.8	>37.3	1.63±0.34	5.10	2.63	9.89
Body energy content at service (MJ)	>4788	<3809	1.11± 0.31	3.04	1.65	5.61
	>4788	3809 – 4288	0.46±0.28	1.58	0.88	2.84
	>4788	4289 – 4788	0.34±0.28	1.40	0.81	2.42
*MYA to peak milk yield (litres/day^{-2})	<0.18	0.18 – 0.34	0.21±0.29	1.24	0.70	2.19
	<0.18	0.35 – 0.68	0.27±0.31	1.31	0.72	2.39
	<0.18	>0.68	0.94±32	2.55	1.35	4.81

R^2 = 0.10 (Cox & Snell), 0.14 (Nagelkerke); Model χ^2 = 50.52, p<0.0001; *SE=standard error; MY=milk yield; MYA =milk yield acceleration; †Note that the model was derived using data that excluded cows that never became pregnant

5.3.2.2 Pregnancy to first three inseminations

Results for random intercept modelling for pregnancy with the first three inseminations for all cows that became pregnant in all lactations varied depending on the predictors included. There was an interaction between genetic merit and feeding system therefore a variable called production system was created. Initially the predictors included were production system, lactation number, days to first observed oestrus (DFH), service milk yield, calving and service BEC. Production system, lactation number, days to first observed oestrus, service BEC and milk yield were significant predictors ($p<0.05$) for pregnancy to the first three inseminations. However, when calving ease and milk yield acceleration were included as predictors, DFH, calving ease and milk yield acceleration were not significant predictors. The odds ratio estimates in Table 5.6 show that average genetic merit cows and cows in their first lactation had the highest chance of getting pregnant with the first three inseminations. Average genetic merit cows were about 2 times more likely to become pregnant than high genetic merit cows suggesting lower fertility in high genetic merit cows.

Table 5.6: Estimates from a random intercept logistic regression model for predictors of pregnancy to the first 3 inseminations[†] in Holstein cows at SRUC Dairy Research Centre

Predictor	P value	Reference	Predictor level	Odds ratio	95% Confidence Limits
Production system	<0.0001	*HFS	LFC	1.5	1.0 – 2.2
			HFC	1.6	1.1 – 2.3
			LFS	0.8	0.5 – 1.1
Lactation number	0.0003	lactation 3	1	2.1	1.5 – 3.1
			2	1.3	0.9 – 1.8
Body energy content at service (MJ)	<0.0001	>4788	<3809	6.7	4.2 – 10.6
			3809 - 4288	2.7	1.9 - 4.0
			4289 - 4788	1.9	1.3 - 2.6
Change in body energy content (%)	0.0008	>2.3%	<-16.2	1.1	0.7 – 1.6
			-16.2 to -7.4	1.9	1.3 – 2.9
			-7.5 to 2.2	0.9	0.7 – 1.3
Service milk yield (litres)	<0.0001	<25.8	25.8 – 31.2	1.7	1.2 -2.5
			31.3 – 37.3	2.2	1.5 – 3.1
			>37.3	4.9	3.1 -7.7
Production system x lactation number	0.0008		-		

*HFC = high forage control; HFS = high forage select; LFC = low forage control; LFS = low forage select; [†]Note that the model was derived using data that excluded cows that never became pregnant

First lactation cows were 2 times more likely to become pregnant to the first three inseminations than cows in their second and third lactations indicating that first lactation cows have higher fertility than cows in the third or more lactation. BEC at serving, BEC change and milk yield at service were also important predictors. Cows with BEC less than 3809 MJ and milk yield of more than 37 litres had greater odds of becoming pregnant with the first three inseminations than cows with higher BEC and lower milk yield. Cows with BEC of less than 3809 MJ and milk yield greater than 37 litres at service had up to 5 and 7 times the chance of becoming pregnant than cows with BEC of more than 4788 MJ and milk yield less than 25 litres per day, respectively. A BEC loss between 7 and 16% between calving and service resulted in an almost 2 times greater chance of a pregnancy than BEC gain of greater than 2.3%. The chance of a pregnancy was not significantly different when BEC loss was greater than 16% and less than 7.5 %. BEC and milk yield at service were also important predictors. The results may reflect that the period with high chance of a successful insemination is around the time of peak milk yield where BEC is lowest.

Results from a logistic model (used in model 2 below) without random effects showed that genetic merit, milk yield, body energy content at service and percentage change in body energy content between calving and service were the significant predictors ($p<0.05$) of pregnancy to the first three inseminations (Table 5.7).

Table 5.7: Estimates from a logistic regression model for predictors of pregnancy to the first three inseminations[†] in Holstein cows at SRUC Dairy Research Centre

Predictor	Reference	Predictor level	Estimate±*SE	Odds ratios	95% Confidence Limits	
					Lower	Upper
Intercept	-	-	-0.52±0.25	-	-	-
Genetic merit	High	Average	0.50±0.18	1.64	1.16	2.32
Milk yield at service (litres)	<25.8	25.8 – 31.2	0.55±0.23	1.74	1.10	2.74
	<25.8	31.3 – 37.3	0.69±0.23	2.00	1.26	3.17
	<25.8	>37.3	1.19±0.26	3.28	1.96	5.49
Body energy content at service (MJ)	>4788	<3809	1.58±0.28	4.84	2.80	8.37
	>4788	3968 – 4288	0.96±0.24	2.61	1.63	4.17
	>4788	4289 – 4788	0.63±0.22	1.89	1.23	2.90
Change in *BEC (%) between calving and service	>2.3%	<-16.2	0.13±0.26	1.14	0.69	1.88
	>2.3%	-16.2 to -7.4	0.68±0.26	2.00	1.19	3.34
	>2.3%	-7.5 to 2.2	-0.04±0.22	0.97	0.62	1.50

R^2 = 0.09 (Cox & Snell), 0.14 (Nagelkerke); Model χ^2 = 85.29, p<0.0001; *SE=standard error; BEC=body energy content; [†]Note that the model was derived using data that excluded cows that never became pregnant

Based on the goodness of fit, models 1 and 2 below were selected for predicting the probability of pregnancy to first insemination and the first three inseminations, respectively.

Model 1

$$Y_1 = ln\frac{p}{1-p} = 0.39000 - 0.37173G - 0.14991L + 0.10921H + 0.29595M + 0.15185E_c - 0.404774E_s \tag{5.8}$$

Where Y_1=the logit of the probability (p) of a pregnancy with the first insemination

p=the probability of a pregnancy with the first insemination

G= genetic merit

L=lactation number

H= number of days to first recorded heat

M= milk yield at service

E_c= body energy content at calving

E_s= body energy content at service

Model 2

$$Y_3 = ln\frac{p}{1-p} = 2.3407 - 0.1827S + 0.3371M - 0.5666E_s \tag{5.9}$$

Where Y_3=the logit of the probability (p) of a pregnancy with the first three inseminations

p=the probability of a pregnancy with the first three inseminations

S= production system

M= milk yield at service

E_s= body energy content at service

Model 1 indicates the following:

- Adjusting for the effects of genetic merit, lactation number, DFH, milk yield at service and body energy content at calving, there would be a 33% decrease (i.e. exp (-0.40474) = 0.67; 0.67-1=-0.33) in the probability of pregnancy to first insemination with every unit increase in the quartiles for body energy content at service. Quartiles 1 to 4 for body energy content at service were <3809, 3809 – 4288, 4289 – 4788 and >4788 MJ, respectively.
- Adjusting for the effects of genetic merit, lactation number, DFH, milk yield at service and body energy content at service, there would be a 16% increase (i.e. exp(0.15185) = 1.16; 1.16-1=0.16) in the probability of pregnancy to first insemination for every unit increase in the quartile of body energy content at calving. Quartiles 1 to 4 for body energy content at calving were <4082, 4082 – 4590, 4591 – 5183 and >5183 MJ, respectively.
- Adjusting for the effects of genetic merit, lactation number, DFH, body energy content at calving, and body energy content at service there would be a 34% increase (i.e. exp(0.29595) = 1.34; 1.34-1=0.34) in the probability of pregnancy to first insemination for every unit increase in the quartile for milk yield at service. Quartiles 1 to 4 for milk yield at service were <25.8, 25.8 – 31.3, 31.4 -37.3 and >37.3 litres, respectively.
- Adjusting for the effects of genetic merit, lactation number, milk yield at service, body energy content at calving, and body energy content at service, there would be a 12 % increase (i.e. exp(0.0.10921) = 1.12;

1.12-1=0.12) in the probability of pregnancy to first insemination for every unit increase in quartile for DFH. Quartiles 1 to 4 for DFH were <44, 44-60, 61 – 83, >83 days, respectively.

- Adjusting for the effects of genetic merit, DFH, milk yield at service, body energy content at calving, and body energy content at service, there would be 13 % decrease (i.e. exp(-0.14991) = 0.86; 0.86-1= -0.13) in the probability of pregnancy to first insemination for every unit increase in lactation number between lactation 1 and 3.
- Adjusting for the effects of lactation number, DFH, milk yield at service, body energy content at calving, and body energy content at service, there would be a 31 % decrease (i.e. exp(-0.37173) = 0.69; 0.69-1= -0.31) in the probability of pregnancy to first insemination if genetic merit changed from average to high genetic merit.

Model 2 indicates the following:

- Adjusting for milk yield and body energy content at service, there would be a 17% decrease (i.e. exp(-0.1827)=0.83; 0.83-1=-0.17) in the probability to pregnancy to the first three inseminations for every unit change in the production system; LFC, HFC, LFS and HFS being production systems 1, 2, 3, and 4, respectively.
- Adjusting for body energy content at service and production system, there would be a 40% increase (i.e. exp(0.3371)=1.40; 1.40-1=0.40) in the probability to pregnancy to the first three inseminations for every unit increase in the quartiles for milk yield at service; quartiles 1, 2, 3 and 4 being <25.8, 25.8 – 31.3, 31.4 -37.3 and >37.3 litres, respectively.
- Adjusting for milk yield at service and production system, there would be a 43% decrease (i.e. exp(-0.5666)=0.57; 0.57-1=0.43) in the probability to pregnancy to the first three inseminations for every unit increase in the

quartiles for body energy content at service; quartiles 1, 2, 3 and 4 being <3809, 3809 – 4288, 4289 – 4788 and >4788 MJ, respectively.

5.3.3 Model validation

Validation of both model 1 and 2 using the remaining dataset from the same herd showed that the models provided a good fit to the data based on the Hosmer-Lemeshow test ($p>0.05$). The AUC was 0.66 with a 95% confidence interval (CI) of 0.57 to 0.75 for model 1 while it was 0.65 (CI:0.55-0.75) for model 2 meaning that the predictions of both models were significantly different from that of chance. Using a cut-off point of 0.55, model 1 was able to correctly identify 68% of the pregnant cows (sensitivity) and 57% of the non-pregnant cows (specificity). Model 2 was able to correctly identify 82% of the pregnant cows and 47% of the non-pregnant cows using a cut-off point of 0.80 (Table 5.8). The cut off points for the two models were different as this depended on the point where sensitivity and specificity of the models were closest to each other.

Table 5.8: Area under the ROC curve (AUC) and sensitivity of pregnancy predictive models for the first insemination and first three inseminations† in the SRUC Langhill and Acrehead herds

Model		Langhill herd		Acrehead herd	
		AUC	Sensitivity (%)	AUC	Sensitivity (%)
Model 1		0.66	68.4 (n=154)	0.69	51.9 (n=105)
	95% CI	0.57-0.75	-	0.54 - 0.84	64.2
Model 2		0.65	81.9	0.68	-
	95% CI	0.55 – 0.75	-	0.43-0.93	-

†Note that the models were derived and validated using data that excluded cows that never became pregnant; CI=confidence interval

Similar results were also obtained for both models when a different herd (Acrehead herd) from the same farm was used to validate the data. The Hosmer-Lemeshow test showed that the models had a good fit to the data ($p>0.05$). The c-statistic of the ROC curve for model 1 was 0.69 with a 95% CI of 0.54 to 0.84. Using a cut-off point of 0.50, model 1 was able to correctly identify 52% of the pregnant cows and 64% of the non-pregnant cows to first insemination (Table 5.8). Although model 2 had a good fit to the Acrehead herd data, the c-statistic of the ROC curve for the model was 0.68 with a CI of 0.43-0.93 meaning that a prediction from this model was not significantly different from that of chance. Hence the results showed that of the two models derived, only the model for predicting pregnancy to first insemination had an acceptable level of accuracy in the Acrehead herd.

5.4 DISCUSSION

The average number of days to first insemination was 72 days. Inchaisri et al. (2011) found that the probability of success for all inseminations increased with days in milk as well as after the time of peak milk yield. Herlihy et al. (2013) also reported similar results. Shahinfar et al. (2014) also found that days in milk at insemination were important in predicting pregnancy outcomes. This effect is attributed to increased oestrus expression, reduction in post-partum disorders as well as recovering from negative energy balance as lactation progresses (Loeffler et al. 1999).

The median of 2 inseminations per pregnancy is consistent with previous reports from the same herd (Pryce et al., 2002) and elsewhere (Inchaisri et al. 2011; Hagiya et al. 2013). Although number of inseminations per pregnancy was similar between high and average genetic merit cows, the days in milk at which successful inseminations occurred varied with genetic merit of the cows as discussed in chapter 4 where average genetic merit cows had significantly lower intervals from calving to successful insemination. This was attributed to lower progesterone production, higher incidences of long luteal phases and relatively higher early embryonic losses in high genetic merit cows (Lucy et al., 1998; Opsomer, 1998; Lucy, 2001; Sheldon et al., 2006).

First lactation cows had higher pregnancy rates than cows in their third or more lactation. These results are in line with findings by (Hagiya et al., 2013; Grimard et al., 2013) that showed that fertility is better in first lactation cows than those in third or more lactation. Grimard et al. (2013) found that energy level, plasma IGF-1 concentrations and conception to first artificial insemination were higher in primiparous than in multiparous cows although oocyte production and quality were not influenced by parity. The study concluded that the influence of energy status on reproductive tissues involved in fertilisation and early embryo development could be more important than oocyte quality to explain the low fertility reported in multiparous cows. Moreover, in the current study first lactation cows had the lowest milk yield at service and change in BEC and service. Inchaisiri et al. (2011) associated lower milk yield at service to successful insemination which could still be linked to the signal for resumption of the reproductive function and subsequent fertilisation and embryo development.

Cows that became pregnant following more than three inseminations had higher service weight, BCS and body energy content and lower milk yield, BCS and BEC loss between calving and service. This was expected, due to the stage of lactation at which the cows achieved successful insemination. The number of days in milk for these cows was about 183 which was well beyond peak lactation and NEB.

5.4.1 Pregnancy prediction

The results on pregnancy prediction were consistent with findings from similar studies (Inchaisri et al., 2011; Shahinfar et al. 2014) and show that the probability of pregnancy to both the first and the first three inseminations were dependent on the stage of lactation and the corresponding magnitude of milk yield and body energy content. The results agree with those of other studies by Kuhn & Hutchinson 2008; Lima et al., 2009; Friggens & Labouriau, 2010; and Inchaisri et al., 2011. In the current study average genetic merit and first lactation cows as well as cows with high milk yield at service were associated with high probability to achieve pregnancy to first insemination. This was also linked to days in milk to peak milk yield and milk yield acceleration. Average genetic merit cows that are known to have higher fertility than high merit cows (as discussed in chapter 4) had about a 50% higher chance for successful insemination than high genetic merit cows. The results further demonstrate that the physiological stress associated with high milk production (Hansen et al., 2006) along with other challenges such as imbalance in hormonal production (Lucy, 2001) and early embryonic loss (Sheldon et al., 2006) in high genetic merit cows has a negative effect on the probability of pregnancy early post-partum.

Lactation, days to first recorded oestrus and calving BEC were only significant in predicting pregnancy to first insemination and not pregnancy to the first three inseminations. This may be because the first insemination was during early lactation when the demand for energy is high and the cows are mostly in negative energy balance. It is during this stage that average genetic merit cows and first lactation have an advantage over high genetic merit cows as discussed above. The results show that including the next two inseminations that occur after peak milk yield and return to positive energy balance show that the effect of parity, DFH and calving BEC are masked. However, the genetic merit and its associated effects on milk yield and service BEC still stand out as important predictors of the outcome of the first three inseminations.

The model developed had accuracy levels of 66 and 65 %, which compares well to some of the accuracy levels reported by Shahinfar et al. (2014) but slightly lower than accuracies of 71% reported by Caraviello et al. (2006) for predicting pregnancy status at 150 days in milk. However, the studies by Caraviello et al. (2006) and Shahinfar et al. (2014) used different prediction methods with larger datasets and variables from different farms while the current study used a relatively smaller dataset from one farm and fewer predictor variables. Hence there may be room for further improvement for the models developed in the current study.

Generally, the study shows that routinely collected data on cow productivity could be used to predict insemination outcomes. The non- significant goodness of fit and ROC curves that were significantly different from chance on the validation dataset suggest that the developed models could provide some degree of guidance in decisions for both the first and first three inseminations. The models in the current study had relatively high sensitivity (68 and 82%, for pregnancy to first and the first three inseminations, respectively) which means the models could, for instance, be used in decisions to inseminate cows with high probability of pregnancy with sexed semen which is often expensive. The high sensitivities are ideal to ensure that high proportions of cows with a high probability of successful inseminations are correctly identified. However, the high sensitivity in the current study was coupled with relatively low specificity (57 and 47%, respectively). This means that about 43 and 53 % of the cows that are not likely to achieve pregnancy with the first and first three inseminations, respectively, would be predicted as likely to achieve pregnancy. The low specificity may therefore confirm the need for further improvement of the models by exploring additional predictors besides predictors included in the current study. Vittinghoff et al. (2012) reported that models including all important predictors among other factors, tend to predict better than models that exclude some important predictors. Considering the complexity of cow fertility discussed in chapter four and above, identifying all important predictors for insemination outcomes may not be straight forward. Hence the models developed from this study provide a starting point from which improvements can be made.

5.5 CONCLUSION

Models developed have a potential to accurately predict the probability of pregnancy to the first and first three inseminations for all cows that ultimately became pregnant but need further refining by adjusting for other possible predictor factors and cows that do not become pregnant at all. The model for predicting pregnancy to first insemination also had acceptable accuracy in a herd under a feeding system that was different from the one used to develop the model. The results generally show that the genetic merit, lactation stage and parity are important predictors of the outcome of inseminations in dairy cattle. Average genetic merit and first lactation cows have a high chance of pregnancy to the first insemination which mostly coincides with early lactation where milk yield is high and body energy content is relatively low. Milk yield acceleration and the magnitude of change in body energy content between calving and service are also important in determining the probability of pregnancy in Holstein cows.

CHAPTER 6: GENERAL DISCUSSION AND CONCLUSION

The study has shown the complementarity of utilising data from both Malawi and the UK in investigating factors that predict fertility in dairy cows. The study was also able to successfully build on the IBSNAT approach described by Uehara & Tsuji (1998) and demonstrated that the aim of achieving improved dairy production in developing countries that have challenges with data availability could, partly, be achieved through utilisation of data from separate populations that are sufficiently similar to enable generation of lessons and further research. The description of the production systems in chapter 3 showed that there were similarities and differences in the production systems involved in the study that enabled comparisons and generation of lessons that could be used to strengthen dairy productivity in both countries. The results in chapter 4 also showed some common trends in traits such as milk yield and fertility traits that were associated with feed quality in both countries. Although results on cow activity were different between the countries, these were attributed to confounding factors in Malawi production systems and effect of production systems on cow activity was ably studied using UK data and used to guide further research in Malawi. The predictive model generated in chapter 5 had acceptable accuracy levels in the UK. The model also highlighted important predictors that could also be tested in Malawi whenever data are available.

Factors that are important for improved dairy cow productivity in terms of milk yield, fertility traits and prediction of insemination outcomes have been identified in the study. The factors include the importance of data quality and availability; the relationship between production systems and fertility; and possibility of accurate prediction of insemination outcomes. Apart from factors listed, the study generated lessons that can be used in both Malawi and the UK for improved dairy production.

6.1 Data Quality

Arts et al. (2002) defined data quality in terms of 'the extent to which registered data are in conformity to the truth' (accuracy) and 'the extent to which all necessary data that could have been registered have actually been registered' (completeness). Data quality and availability are important aspects in dairy production to enable valid research and appropriate monitoring and evaluation of dairy productivity. In view of this, many countries have established recording systems (ICAR, 2012) but in Malawi such recording systems have not been fully established. Data availability and quality in some aspects of the research were limiting as discussed in chapters 3 and 4. The limitations included a small number of study animals, less reliable recording systems and the wide variability in management systems. However, the data from Malawi still provided valid results and where results were inconclusive a hypothesis in question was tested using more reliable data from the UK. Among the valid results were data on milk yield and fertility where cows fed higher quality feeds performed better, similar to cows in the UK. Tables 4.4, 4.5 and 4.9 in chapter 4 showed that cows from both Malawi and the UK that were fed high quality concentrates or rations had significantly higher milk yield and fewer days to first high luteal activity. These results were supported from literature where it is reported that a higher plane of nutrition enables increased nutrient availability for milk synthesis and to support resumption of cyclicity (Robinson et al., 2006; Leroy, 2010a).

Results on cow activity demonstrated the complementarity of the data from Malawi and the UK. In Malawi cows on low energy diets had low activity but the results were confounded by housing hygiene and inconsistent feeding systems.

A hypothesis on the relationship between energy content in the diet and cow activity was tested on UK cows on home grown and by-product feeding systems. The results confirmed that there were indeed differences in cow activity that could be attributed to body energy status. However, it was the cows fed diets with relatively lower ME and CP that were more active and spent more time standing and eating than those on diets with higher ME and CP. Their greater activity was probably to increase feed intake to counter negative energy balance.

There is still further need for a more detailed study in Malawi to determine if what was demonstrated in the UK in terms of energy balance could be similar in Malawi while controlling for the confounding factors. If this is confirmed it would then enable development of a tool to quickly detect cows that need adjustment in their feeding regime before problems in feeding translate into losses in terms of milk yield and fertility. Since cows in the UK herd under study are already fitted with accelerometers that monitor activity, the monitoring of body energy status may just need further detailed studies and development of thresholds at which system alerts may be created when there is need for attention to individual cow energy status.

Data from the UK were more reliable and enabled generation of more reliable statistical inferences. This was because the data involved large numbers of animals with less variation in management systems coupled with consistent long term accurate recording. The management of animal feeding, breeding and health were according to standard operating procedures that were well maintained and regularly assessed by independent audits according to national legislation. This ensured well maintained animal welfare and quality assurance. Such an approach is lacking in Malawi dairy production systems and ought to be adapted in developing the Malawian recording systems. However, data from the

Langhill herd may not truly be a representative of the average UK dairy farms as the Langhill herd is a long term experimental herd. It would be worthwhile for future studies to include data from other dairy farms within the UK for more comparisons and lessons.

Availability of reliable data from the UK also made it possible to identify factors that influence fertility which were also monitored in Malawi. Although data collection in Malawi had numerous challenges, the study was able to successfully monitor the traits and demonstrated similar results to the UK although the magnitude of the variables were different as expected due to differences in management system and other environmental factors. For instance the interval from calving to first high luteal activity and first observed oestrus were similarly related to feeding systems both in the UK and Malawi. The approach enabled aspects that needed more attention in both Malawi and the UK in order to improve cow fertility and milk production to be identified. The importance of feeding systems in relation to fertility was clearly established where energy status at service came out as one of the major determinant of the outcome of an insemination. Energy status data were obtained through calculations using body weight and condition score data (Banos et al., 2006). Although the calculations may not be easily done on farm, the data may be made readily available through user friendly tables such as in the example presented in Table 6.1.

Table 6.1: Body energy content (MJ) conversion table derived from body weight and condition scored in dairy cows

Weight (kg)	Body condition score on a scale of 1 to 5						
	2.00	2.25	2.50	2.75	3.00	3.25	3.50
400	2864	3081	3297	3513	3729	3946	4162
450	3222	3466	3709	3952	4196	4439	4682
500	3580	3851	4121	4392	4662	4932	5203
550	3938	4236	4533	4831	5128	5425	5723
600	4297	4621	4945	5270	5594	5919	6243
650	4655	5006	5357	5709	6060	6412	6763
700	5013	5391	5770	6148	6527	6905	7284
750	5371	5776	6182	6587	6993	7398	7804
800	5729	6161	6594	7026	7459	7892	8324

Highlighted figures show body energy content at service that is potentially optimal for a successful pregnancy to first insemination based on study findings.

Based on the prediction model, the optimal level of body energy content at service for successful pregnancy to first insemination was determined to be between 2800 and 4000 MJ. However, the body energy has to be adjusted for genetic merit, parity, milk yield and milk yield acceleration as presented in the model.

6.2 Production system and fertility

Genetic merit and feeding system were determined as the key factors that influenced fertility. There was a significant interaction between the two factors such that improvement in nutritional quality resulted in improved fertility as demonstrated in Table 4.9. For instance, the days to first high luteal activity and calving interval in cows of either high or average genetic merit fed a low forage diet were significantly shorter than those fed high forage diets. Low forage diets had higher CP and ME than high forage diets as discussed in chapter 3. Similarly in Malawi high feeding levels resulted in fewer days to first high luteal activity and observed oestrus than low feeding levels (Table 4.11). The results confirm previous reports by Pollott & Coffey (2008) and show the importance of feeding dairy cows based on their requirements for maintenance and production. This information is particularly important in Malawi where feeding dairy cows was not based on these requirements as discussed in chapter 3.

6.3 Prediction of insemination outcomes

Models for predicting the probability of pregnancy with the first insemination and the first three inseminations were successfully developed and validated using UK data and showed an acceptable level of accuracy. The models could therefore be used, for instance, in decisions to inseminate cows with a high likelihood of pregnancy with sexed semen which is often expensive. However, there is room for further improvement of the models through further exploration of other factors that were not included in the development of the current model. Among these factors could be milk urea nitrogen and milk fat-protein ratio which have also been related to fertility (Rajala-Schultz et al., 2001; Negussie et al., 2013). Further work on model development also ought to consider including cows that never become pregnant troughout the breeding period.

The study has successfully developed a framework which could also be tested and validated when data are available in Malawi. Use of such a model in Malawi could help efficient decision making on whether to inseminate cows with expensive imported semen, relatively cheap locally available semen or to serve particular cows with bulls given a particular predicted probability of the outcome of an insemination.

6.4 Lessons

Despite the challenges with data from Malawi, there were some lessons that could be drawn from Malawi dairy systems which could be applied in the UK. One of these was the categorisation of smallholder farms according to management systems in order to more appropriately assess and develop appropriate interventions for the farms. This approach could, for instance, be used in the UK farm assurance scheme to categorise dairy farms into low, medium and high risk farms in order to more efficiently assess the farms. The farm assurance scheme in the dairy industry conducts statutory inspections of dairy farms to assess compliance with farm assurance standards. Based on these audits, bonuses and penalties are applied to individual farms (Bailey & Garforth, 2014). The current approach deals with farms as if they were a homogeneous group where all dairy farms are assessed every 15 to 17 months. However, Van Asseldonk & Velthuis (2013) reported that such a traditional approach to audit all farms at specified periods may be costly in terms of resource use. Van Asseldonk & Velthuis (2013) provided evidence that farm audits could be conducted on a risk-based system where high risk farms are audited more frequently than low risk farms. Such an approach may not only be used for quality assurance assessments but also for efficient delivery of other services such as extension and health services.

Another lesson relates to the involvement of commercial farms in research which had benefits in that large numbers of cows were readily available for data collection in Malawi. However, there could be other costs and risks in terms of availability and reliability of data when other data and activities appropriate for accurate data collection may not be of direct financial benefit to the farms, in the short term. For instance, at Mapanga Dairy Farm in Malawi there was need for records on milk yield, milk fat and protein, oestrus dates (including during the voluntary waiting period), insemination dates, weekly weights and body condition scores for all cows. However, not all these data were available, instead only milk yields and oestrus dates at insemination were readily available. Recording of weekly weights and body condition scores were initiated during the study period while measurement of milk fat and protein could not be done as it required some equipment to be bought. Milk fat and protein recording is not a routine practice in Malawi as milk is not sold based on quality. Hence research involving commercial farms may require striking a balance between farm and research objectives along with rigorous and consistent monitoring to ensure the availability and reliability of the data. The current study also demonstrated the practical use of data on body weights and condition scores and provided an opportunity for Mapanga Farm to adopt routine recording of the traits and using them to evaluate cow productivity.

6.5 Conclusion and recommendations

It is concluded that genetic merit, feeding system, parity, energy status and stage of lactation are the major factors that determine achievement of pregnancy at a particular insemination. Some of the factors associated with success of an insemination in the UK were ably monitored in Malawi although there were some challenges in the accuracy and frequency of data collection. The factors that were successfully monitored were feeding systems, milk yield and intervals from calving to first high luteal activity, first observed oestrus and insemination. Feeding systems and genetic merit were also determined to be important factors that influence cow activity and fertility. Models to predict the likelihood of pregnancy following an insemination were successfully developed and validated using data from the UK but could not be tested on data from Malawi. However, further research is needed for more details on the association between cow activity, energy status and feeding behaviour of cows as well as further improvement of the predictive models developed.

It is recommended that strict animal and data management protocols be developed and monitored in both smallholder and large scale farms in Malawi to enable not only improved dairy cow productivity but also develop and implement effective dairy monitoring and evaluation tools. The UK dairy industry may also adapt the categorisation of farms according to management systems to enhance efficient resource utilisation in farm audits and service delivery.

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APPENDICES

Appendix 1: Baseline survey questionnaire

Smallholder dairy farming in Lilongwe & Dedza Districts

HOUSEHOLD QUESTIONNAIRE

District………………………………… EPA: ……………………………………..

T.A. …………………………………… Village: …………………………………..

MBG ……………………………………………………..

Name of interviewer: ……………………………………………………………………

Signature: …………………………….. Date………………….

Checked by ……………………………………………………………………

Signature: ……………………………. Date ………………….

DEMOGRAPHIC DATA

1. Name of respondent:.…………………………..…………………………………..
2. Gender of respondent: 1. Male 2. Female
3. Gender of household head: 1. Male 2. Female
4. Name of head of household: ……………………………………………………………
5. Name of dairy farm owner: ……………………………………………………………
6. Household's characteristics

Questions	Codes	Response
Age of household head	Actual number of years	
Age of dairy farm owner	Actual number of years	

Questions	Codes	Response
Marital status	*1=Married; 2=never married; 3=Divorced; 4=Widowed; 5=separated;*	
Level of education? (specify level)	*1=no formal education; 2=primary education (P1-P8); 3=secondary education (F1-F4); 4=completed high school certificate; 5=diploma and degrees; 6=other (specify)*	
Type of residential main house	*In terms of Roof (1= thatch,2= iron sheets)*	
	In terms of Walls (1=unburnt bricks 2= burnt bricks 3= sticks and mud)	
	In terms of Floor 1=(mud 2= cement)	
How many people currently live in this household including yourself?		
	Adult (F+M) aged 50+	
	Adult (15-50)	
	Young (10 – 14)	
	Children (0-9)	
	Total	
What is your primary occupation?	*1=dairy farming; 2=crop production; 3=salaried worker;4=ganyu/piece work; 5=other (specify);*	

DAIRY PRODUCTION

7. When did you start dairy cattle production? Year: ……………… Month: …………………
8. How did you obtain the animals? 1=cash loan; 2=own cash; 3=in-kind loan; 4=own local animals; 5=other (specify) ………………………………………
9. If it was through a loan, what was the source of the loan?

   1=NGO (specify)………………………………; 2=Project (specify) …………………………….; 3= govt.; 4=bank (specify)………………………………………; 5=other (specify)………………………………………
10. If used cash, how much was the initial amount? ....
11. If capital loan was in kind, what was received? 1=pregnant heifer; 2=pregnant cow; 3=heifer; 4=cow; 5= other (specify) ………………………………………

12. How will/have you paid back?

………………………………………………………………………………..

…………………………………………………………………………………………

13. How many dairy animals did you start with? Specify in the table below

Breed	Cows	Heifers	Pregnant heifers	Pregnant cows	Bulls	Calves		Total
						M	F	

Codes for breed: 1=Holstein/Friesian; 2=Jersey; 3=Holstein x local cross; 4=Jersey x local cross; 5=local; other (specify)

14. How many dairy animals do you have currently? Specify in the table below

Breed	Cows	Heifers	Pregnant heifers	Pregnant cows	Bulls	Calves		Total
						M	F	

Codes for breed: 1=Holstein/Friesian; 2=Jersey; 3=Holstein x local cross; 4=Jersey x local cross; 5=local; other (specify)

BREEDING AND RECORD KEEPING

15. How do you serve your animals?

1=AI   2=own bull   3=hired bull   4=other (specify)

16. If animals are served through AI, fill the table below

AI done by 1=farmer AI technician 2=govt AI technician 3=other (specify)	Charge per insemination (MK)	How do you report heat? 1=phone call ; 2=sms 3=cycle to AIT ; 4=walk to AIT; 5=send message (specify time taken for 3, 4 & 5)	How long does it take for the technician to come?	Who does PD? 1=farmer technician 2=govt AI technician 3=owner 4=other (specify) 5=PD not done	After how long from AI is PD done?

17. If animals are served by a bull, fill the table below

Source of bull 1=own 2=hired 3=borrowed	Breed	Charge of bull if is hired,(MK)	How long it is kept per hire?	Who does PD? 1=farmer technician 2=govt AI technician 3=owner 4=other (specify) 5=PD not done	After how long from service is PD done?

18. How is a bull selected? 1=type of breed (specify); 2=cheaper hiring rate; 3=accessibility; 4=extension recommendation; 5=conception rates; 6=progeny characteristics; 7=other (specify) ………………………………………………………………

19. What are the reasons for using a bull? 1=lack of AI technician; 2= AI not successful; 3=scarcity of semen; 4=AI is expensive; 5=high conception rate; 6=other (specify)…………………………………………………………………………..

20. What are the problems faced with using a bull? 1=bull not available; 2=bulls on high demand; 3=disease transmission; 4=hiring is expensive; 5=extra feeding cost; 6=other (specify) ………………………………………………………

21. Do you keep records on dairy cattle production? 1=Yes 2=No

22. If no, why? ……… ……… ……… …………………..

23. If yes, what kind of records? 1=milk sales; 2=drugs; 3=feeds; 4=breeding; 5=disease treatment; 6=body condition score; 7=vaccinations; 8=milk yield; 9=animal sales; 10= births; 11=deaths; 12=other (specify) ……………………………………………………………

24. If keeping records on breeding indicate if the following are recorded

Type of records	1=yes 2=no
Insemination date	
Inseminator	
Semen straw bull ID	
Source of semen	
Bull ID (natural mating)	
Mating date	

25. How do you identify your animals? 1=names 2=tags 3=other (specify) …………………

26. On the cows and/or heifers that you have, report the following

Animal ID	Date acquired	Date of birth	Date of last service	No. of services per conception	No. calves born alive	No of abortions	No. of still births	No. of calves weaned	Age at weaning (months)

27. For the cows you have, provide the most recent information in the table below

	cow ID	cow ID	cow ID	cow ID
Previous calving date				
Insemination date				
2nd insemination date				
No of inseminations				
PD date				

Dry off date				
Current calving date				
Insemination date or expected date				
2nd insemination date				
No of inseminations				
PD date or expected date				
Dry off date or expected date				

28. Have you had any cases of dystokia? 1=Yes 2=No

29. If yes, fill the table below

How many cases?	Severity of problem 1= slightly easy; 2= slightly difficult; 3=difficult; 4=very difficult; 5=severely difficult	How was each dystokia case handled? 1=animal assisted by farmer; 2=animal assisted by vet; 3=animal left alone; 4=other (specify)	Did the calf survive? 1.Yes; 2.No
1st case			
2nd case			
3rd case			

MILK PRODUCTION

30. For milk production provide the following details for the most recent complete lactation:

Cows	cow ID	cow ID	cow ID	cow ID
Calving date				
Milk yield/day at onset (litres)				
Milk yield/day at peak (litres)				
Milk yield/day at end (litres)				
Lactation length (months)				

HOUSING

31. Ask, observe and fill the table below on housing

Hygiene	Floor		Roof	Feed store	Feeding troughs	Water troughs	Milking parlour	Drainage
	Type	Slope						
Codes 01=clean 02=dirty	**Codes** 1=concrete+beddings 2=concrete 3= mud 4=Mud+ beddings 5=sand 6=sand + beddings 7=other specify	**Codes** 1=flat 2=slanting	**Codes** 1=Not roofed 2=adequately roofed with iron sheets 3=adequately roofed with grass +plastic sheet 4= adequately roofed with grass only 5=inadequately roofed	**Codes** 1=present 2=absent	**Codes** 1=present 2=absent	**Codes** 1=present 2=absent	**Codes** 1=present 2=absent	**Codes** 1=good 2=poor

32. How often you do you clean the house? Fill the table below

	Resting area	Feeding troughs	Water troughs	Milking parlour
How often is it cleaned?				
How often are changes made for the following?	Beddings:	Feed:	Water:	
Codes 1= once a day; 2=once a week; 3=not done; 4=other (specify)				

FEEDS AND FEEDING

33. What kind of feeding system do you follow?

1= herded grazing& supplementation; 2=cut & carry +supplement; 3=herded grazing; 4=others (specify)

34. If supplements are provided, what type of supplements?

1=maize bran; 2=maize bran + salt; 3=dairy mash; 4=locally made ration; 5=mineral lick; 6=other (specify) …………..

35. How often is the supplement given? 1=once a day; 2=two times a day; 3=other (specify) ……………………...

36. Is the quantity of the supplement measured? 1=Yes; 2=No

37. If supplement is measured, how much is given per feeding per animal? …………………… kg

38. How much water are the animals given? .... litres

39. How often is the water given? 1=ad lib; 2 =once a day 3 = twice a day 4=other (specify) ....

40. What is the water source for the animals? 1=protected well; 2=unprotected well; 3= borehole; 4=tap; 5=river/stream; 6=other (specify ....)

41. Have you established any pastures? 1=yes 2=no

42. If yes, what kind of pastures? Fill the table below:

Type of pasture 1=Rhodes grass; 2=Napier grass; 3=Centrosema ; 4=Silver leaf; 5=Acacia 6=Leucaena ; 7=other (specify)	Category 1=grass; 2=legume; 3= multi-purpose tree species 4= combined (specify.)	Area (acres)	How long have you had the pastures	How long does it last?

43. Do you conserve any feeds? 1=yes 2=no

44. If yes, what kind of feed conservation methods do you use for different kinds of feeds?

Type of feed 1=grass; 2=maize stover; 3=groundnut haulms; 4=other (specify)	Conservation method 1=hay; 2=silage; 3=other (specify)	Season conserved 1=dry; 2=wet; 3=both seasons	Season used 1=dry; 2=wet; 3=both seasons

ANIMAL HEALTH

45. What are the major disease challenges that you face? 1=Mastitis (MS); 2=Brucellosis (BC); 3=diarrhoea (DR); 4=TB; 5=FMD; 6=black quarter (BQ); 7=ECF; 8=other (specify) …………………………………..

46. In the past year (2010) and this year (2011), which of the diseases stated above did you encounter?

Disease	Month & year	Duration	Treatment 1=yes 2= no	Who treated? 1=AVO 2=owner 3=other specify	How did you report? 1=phone call 2=cycle to AIT ; 3=walk to AIT; 4=send message	How long did it take for treatment to be given?	How much were you charged?

47. Are there any specific reproductive diseases/disorders that you know? 1=yes; 2=no

48. If yes, what are they? ……

49. Have you experienced any on your farm? 1=yes; 2=no

50. If yes, specify ……

51. How do you access drugs for your animals?

    1= through AVO 2=drug revolving scheme 3=do not treat 3=other (specify)

52. If animals are not treated, why? 1=expensive drugs; 2=drugs unavailable; 3=AVO not available; 4=other (specify ………)

53. If animals are not treated using drugs, how do you control diseases?

    1=traditional medicine; 2=call for vet; 3=slaughter sick animals; 4=sell sick animal; 5=isolate sick animals; 6=other (specify)

ACCESS TO INPUTS

54. What inputs to dairy cattle production did you access in 2010 and 2011?

2010				2011			
Inputs	Source	Cost	Constraints	Inputs	Source	Cost	Constraints

Codes for inputs

1=AI (fee +straw); 2=physical breeding animal; 3=drugs (specify); 4=vaccine; 5=animal feed (specify); 6= hire of bull ; 7=none; 8=AI fee; 9=semen straws 10=Others (specify)

Codes for source

1=AVO; 2=AI technician; 3=Village drug box; 4=private shop; 5=market; 6=NGO (specify); 7=other farmers; 8=MBG 9=other (specify)

Codes for constraints

01=in availability; 02=high prices; 03=inadequate; 04=none; 05= Others (specify)

ACCESS TO EXTENSION SERVICES

55. Have you received any training in dairy cattle production? 1=yes 2=no

56. If yes, fill the table below

Area covered 1= disease control 2=feeding 3=feed formulation 4=housing 5=breeding 6=recording 7=other (specify)	When?	Duration	Who provided the training 1=EPA staff; 2=NGO(specify) ; 3=Project (specify)

57. Do you have access to dairy cattle extension services? 1=Yes 2=No

58. If yes, who is the service provider? 1=Govt; 2= NGO (specify ....) 3=lead farmer; 4=Other (specify ....)

59. If yes, what areas of animal husbandry are covered by extension? Fill the table below

Areas covered 1=Feeding ; 2=Housing ; 3=Breeding ; 4=Record keeping; 5=Animal health; 6=other specify)	Service provider 1=AEDOs 2=AVOs 3=NGO (specify) 4=other (specify)	How is it provided? 1=on demand; 2=scheduled	If scheduled, how often? 1=fortnightly 2=monthly 3=other (specify)	Are you satisfied with the service? 1=yes 2= no	Reasons for satisfaction/dissatisfaction

60. Do you have any other comments?

……
……
…………………..

THANK YOU VERY MUCH FOR YOUR TIME!

Appendix 2: Form for fortnightly smallholder dairy farm monitoring

SMALLHOLDER DAIRY CATTLE PRODUCTION MONITORING FORM

District: ………………………………… Village: ………………………………..

Name of Farmer: ………………. Code: ……. MBG ……………………………..

Date ……………………………………… Recorder ………………………………

NO.	**OBSERVATION**	**SCORE CODES**	**SCORE**				**COMMENTS**
ANIMAL VISUAL ASSESSMENT			**Cow ID**	**Cow ID**	**Cow ID**	**Cow ID**	
1	Claw abnormalities	1= present 2=absent					
2	Claw cleanliness	1=clean (no presence of manure) 2=Lightly soiled (minor splashing)					
3	Coat cleanliness	3=Soiled (plaques of manure) 4=Heavily soiled (confluent plaques of manure)					
4	Attitude	1=alert 2=apathetic					
5	Eye abnormalities	1= present 2=absent					
6	Muzzle wounds, sores or hair loss	1= present 2=absent					
7	Lesions	1= present 2=absent					
8	Swellings	1= present 2=absent					
9	Hair loss on flank/body rear	1= present 2=absent					
10	Heart girth	cm					

<table>
<tr><td>11</td><td colspan="2">BCS</td><td>Score 1-5</td><td></td><td></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td colspan="5">MANAGEMENT AUDIT</td><td></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td>12</td><td colspan="2">Floor status</td><td>0=wet & dirty 1=wet & clean 2=dry & dirty 3=dry& clean</td><td colspan="4"></td><td colspan="2"></td></tr>
<tr><td>13</td><td rowspan="2">Wate r</td><td></td><td>1= Present 2=Absent</td><td colspan="4"></td><td colspan="2"></td></tr>
<tr><td>14</td><td>Cleanliness</td><td>1=dirty 2=clean</td><td colspan="4"></td><td colspan="2"></td></tr>
<tr><td>15</td><td rowspan="6">Feed</td><td>Forage</td><td>1= Present 2=Absent</td><td colspan="4"></td><td colspan="2"></td></tr>
<tr><td></td><td>Time</td><td>Indicate exact time of the audit</td><td colspan="4"></td><td colspan="2"></td></tr>
<tr><td>16</td><td>Chopping size</td><td>1=not chopped 2=too big 3=good</td><td colspan="4"></td><td colspan="2"></td></tr>
<tr><td>17</td><td>Dryness</td><td>1=too dry 2=too moist 3=good</td><td colspan="4"></td><td colspan="2"></td></tr>
<tr><td>18</td><td rowspan="2">Concentrate</td><td rowspan="2">1=maize bran 2=maize bran+salt 3=dairy mash</td><td rowspan="2" colspan="4"></td><td>Amo unt /day (kg)</td><td>How many times</td></tr>
<tr><td>19</td><td></td><td></td></tr>
<tr><td colspan="4">MILK QUALITY TEST</td><td>No. of passes/week</td><td colspan="3">No of rejections/week</td><td colspan="2"></td></tr>
<tr><td></td><td colspan="2"></td><td>Circle the appropriate or both</td><td></td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>20</td><td colspan="2">Alcohol</td><td>1=Passed 2=Failed</td><td></td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>21</td><td colspan="2">Specific density</td><td>1=Passed 2=Failed</td><td></td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>22</td><td colspan="2">Visual / Organoleptic</td><td>1=Passed 2=Failed</td><td></td><td colspan="3"></td><td colspan="2"></td></tr>
</table>

Appendix 3: Refereed journal article - Banda et al. (2012)

This Appendix contains a copy of the following research article:

Banda, L. J., Kamwanja, L.A., Chagunda, M.G.G., Ashworth, C.J. and Roberts, D.J. 2012: Status of dairy cow management and fertility in smallholder farms in Malawi. Tropical Animal Health and Production. Volume 44, Number 4 (2012), 715-727

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Trop Anim Health Prod (2012) 44:715–727
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REVIEW ARTICLE

Status of dairy cow management and fertility in smallholder farms in Malawi

Liveness Jessica Banda · Leonard A. Kamwanja · Mizeck Gift G. Chagunda · Cheryl J. Ashworth · David J. Roberts

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Abstract A review of the smallholder dairy production in Malawi was conducted using livestock annual reports and other literature that was supplemented with primary data from a baseline survey conducted in December 2009. Smallholder dairy farming in Malawi operates with support from institutions that facilitate access to initial stock and dairy production technologies. Most farmers (94%) keep the animals in pens where feed is provided throughout the year. Results indicated unsatisfactory feeding, housing and health management practices, which negatively impact cow fertility. Dairy population trends suggest low replacement rates, which could be associated to low cow fertility and inadequate management skills. There are challenges related to access to breeding and health services, which further contribute to low productivity. Low fertility is evidenced by low calving rates (22–61%) and long calving interval (405–549 days). Existence of programmes on farmer capacity building provides an opportunity for improved management skills and cow productivity. It is concluded that dairy cow management and fertility have challenges and opportunities that are influenced by the extent to which farmers have access to important services such as extension, health, breeding and finance.

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Keywords Dairy · Fertility · Calving rate · Calving interval · Management · Smallholder

Introduction

Malawi is in Southern Africa and lies between latitudes 9º22′ and 17º03′ S and longitudes 33º40′ E and 35º55′ E. It is characterized by tropical climate with two distinct seasons, which are rainy and dry seasons with annual rainfall ranging from 700 to 2,400 mm (FAO 2006). Mean annual temperatures vary between 10°C and 25°C depending on altitude, which ranges from 37 to 3,000 m above sea level (Reynolds 2000). Dairy production is an important enterprise in Malawi and comprises a few large-scale farms and smallholder farms. The difference between large and smallholder farms is mainly determined by herd size, breeds raised and management level (Chagunda et al. 2006). Large-scale farms keep large herds of pure dairy breeds and involve high inputs in terms of land, labour, housing, feed and health management. There are about five large farms owning about 12,000 animals (Imani Development Consultants 2004). The Holstein–Friesian is the major breed available in large-scale farms, with a few Ayrshires and Jerseys (Chagunda et al. 2006; Chintsanya et al. 2004). Animals are bred through artificial insemination (AI) using imported semen, with a few standby bulls. The farms grow forages for grazing and make silage and hay. Concentrates are generally based on groundnut, cottonseed and sunflower cakes, maize, soybean and mineral supplements (Chintsanya et al. 2004).

Smallholder farms keep a few animals that are mostly crossbreeds using a low input production system. There are currently, over 8,000 smallholder dairy farmers (Chimbaza 2011) owning about 40,494 dairy cattle (Department of

Animal Health and Livestock Development (DAHLD) 2010). The farmers generally practice mixed crop–livestock production systems (Chagunda et al. 2006) with crops mostly being the primary production. The farmers are organized into milk bulking groups where they collectively sell milk to processors. They receive support from government and non-governmental organizations (NGOs) such as Land O' Lakes and Small-Scale Livestock Promotion Program. The support from the institutions includes access to initial stock and improved dairy technologies. Technologies included are on feeding, housing, health and breeding. The support plays an important role as most farmers may not be able to generate sufficient initial capital on their own to profitably engage in dairy farming (Chindime 2008). In terms of stock, government mostly provides one half Holstein–Friesian × Malawi Zebu crosses, while most NGOs provide pure breeds of Holstein–Friesian or Jersey. The crosses from government are bred within government farms (Gondwe 2011) while pure breeds are imported. The subsector has registered a rapid increase in the past 6 years (DAHLD 2009). The rapid growth of the subsector could largely be attributed to support from NGOs and government projects that target dairy production among smallholder farmers.

Despite the rapid growth, the smallholder dairy sector is faced with several challenges. These include limited breeding stock, low productivity, poor management and inadequate access to extension, health and other support services (Goyder and Mang'anya 2009). These challenges have negative impacts on milk productivity and reproduction (Chagunda et al. 2010). With respect to reproduction, the main challenge is low fertility. Reports from one of the high milk-producing areas, Blantyre Agricultural Development Division (BLADD) indicate that calving percentage in 2007 was as low as 30% (BLADD 2008). Fertility is defined by Mukasa-Mugerwa (1989) as the ability of animals to produce healthy offspring in abundance. The trait has two components: firstly, the heifer or cow showing normal oestrous cycles and, secondly, establishing and maintaining pregnancy following artificial insemination or natural service (Lovendahl and Chagunda 2010). For the smallholder dairy cattle producer in Malawi where record keeping is poor (Chagunda et al. 2006), the most practical estimate of fertility is the percentage of mated or inseminated cows that become pregnant (pregnancy rate) or finally calve (calving rate). Pregnancy rate is mainly assessed through failure to return to oestrus.

It is important that the major factors associated with low fertility are identified and addressed as fertility determines herd growth and productivity in terms of milk sale per year. Herd growth may not be the target for most smallholder farmers as keeping more animals may not be practical and economically viable. However, successful reproduction is still important as the farmers benefit through continued milk production and sales of weaned calves. The current paper analyzes the situation and outlines future prospects of smallholder dairy cattle production system in Malawi in relation to cow fertility and outlines major challenges and possible solutions. It is anticipated that the information generated could be used as a basis for interventions to improve dairy cattle productivity among smallholder farmers.

Methodology

A review of the smallholder dairy cow management and fertility was conducted using annual reports from DAHLD and other literature. Most studies on dairy production in Malawi report on the general production system and related challenges with little or no information on cow fertility. Therefore, the review used any information that could directly or indirectly be related to cow fertility to analyze the current status of cow fertility. Reports from DAHLD also provided some raw data on some aspects of fertility, mainly, cow inseminations and births. These data were from three agricultural development divisions (ADDs), Lilongwe, Blantyre and Mzuzu (Fig. 1), which house the major milk-shed areas in Malawi. Descriptive statistics were generated from the data, and comparisons were made between ADDs over a period of 3 years. Challenges and opportunities reported were also compared, and inferences were made based on this information. The productivity status was further compared to study findings from similar production systems in the tropics.

The data from literature and the survey enabled the paper to provide an overview of cow management and fertility in smallholder farms. Feeding, housing and breeding management was analyzed and related to the nutrition, health and fertility status of the cows. Calving rate and calving interval were analyzed to represent the direct indicators of fertility. Calving rate or percentage is defined as 'the percentage of breedable females which calve during a given year' (Perera 1999), while calving interval is the period between two consecutive calvings (Gietema 2005). Other commonly used measures of fertility such as submission rates, conception rates and conception to calving interval could not be used as they require detailed recording, which does not currently occur among the smallholder farms surveyed. Data on the dairy herd structure of the three ADDs from 2007 to 2010 were entered in Microsoft Excel 2007 and exported to SAS 9.1 where calving rates were calculated and analyzed using the general linear model at 5% probability. Calving interval data were only reported in 2009 in Blantyre ADD. Means were calculated in Microsoft Excel 2007, and the data were not subjected to further analysis as the dataset was too small.

Fig. 1 Map of Malawi showing the agricultural development divisions

The literature was supplemented with primary data obtained from a baseline survey conducted in selected smallholder dairy farms between December 2009 and January 2010. The farms represented the Central (Lilongwe and Kasungu), Southern (Thyolo) and Northern (Mzimba) milk-shed areas. Data were collected using structured and semi-structured questionnaires that were administered to individual dairy farming households and key informants, respectively. A total of 163 dairy farmers were interviewed where 14, 40, 43 and 66 were from Kasungu, Lilongwe, Thyolo and Mzimba Districts, respectively. District and EPA extension staff as well as local leaders served as key informants. Management practices in animal breeding, record keeping, milk production, feeding, housing and health were recorded. Access to inputs and other services such as extension and health was also investigated along with challenges and perceived solutions to challenges outlined. Individual farms also reported on how long it took to inseminate the animals after calving. This information was used to give a rough indication of the calving to conception interval.

The baseline survey data were entered and analyzed in SPSS 15.0 where descriptive statistics that included means, percentages, frequencies and crosstabs of variables were generated. Chi-square and analysis of variance were used to determine differences between districts at 5% probability. Differences between means were assessed using the Student–Newman–Keuls multiple comparisons test.

Results and discussion

Feeding system

The baseline survey showed that the majority of smallholder farmers (94%) use zero grazing feeding system. Only a few farmers in Lilongwe (4%) and Mzimba (2%) used herded grazing. In the zero grazing system, cows are kept in pens throughout the year, and feed is always provided for them. Maize bran was the major type of concentrate that most farmers (96%) provided to the animals. Most farmers had established pastures (76%). Significantly fewer ($p<0.05$) farmers (37%) had pastures in Thyolo than in Lilongwe (95%), Mzimba (87%) and Kasungu (86%). This could be attributed to land being a limiting factor in Thyolo. A considerable proportion of farmers (65%) conserved feeds, and most of these were from Mzimba (25%) and Lilongwe (21%). The types of pastures were mainly grasses as evidenced by Napier (*Pennisetum purpureum*, 89%) and Rhodes (*Chloris gayana*, 10%) grass from the survey. These results are similar to findings from the central and northern milk-shed areas by Chindime (2008) where 94% and 5% of the farmers utilized Napier and Rhodes grass, respectively. The prevalence of Napier grass could be related to the high dry matter (DM) yields, which are more than most tropical grasses (Orodho 2006).

Legumes, which are important forages in supplementing protein, do not seem to be routine practice (Mtimuni 2011) although their use by smallholder farmers has been reported (Chakeredza et al. 2008; Chindime 2008). The reports, however, do not specify the quantities fed and the actual feeding practices. Fodder legume production has challenges such as inaccessibility of planting materials and farmers not appreciating their importance (Chindime 2008). Promotion of legume production coupled with proper demonstrations and diet formulation could be used to improve dairy cattle feeding. Access to financial resources has also been found to play an important role in dairy feeding technology adoption. Use of supplements such as dairy mash, molasses, legumes and minerals was positively associated with farmers that had access to credit (Chindime 2008). This implies that proper dairy management is dependent on several factors, and it is important that basic services such as extension and finance be made available so that other specific factors that need to be addressed are not masked.

The sizes of the pasture plots are often inadequate to provide feed throughout the year. From the baseline survey, plot sizes averaged 0.26 ± 0.19 ha with a median of 0.2 ha. Assuming an average DM yield of 16 t/ha/year (Orodho 2006), the Napier grass DM yield per year would be 4.2 t in these plots. For a lactating cow weighing 500 kg, required daily DM intake would be 15 kg (Orodho 2006), and this forage would last for about 9 months. Given that farmers tend to own more than one cow, the forage supply would last much less than 9 months. In addition, the feed presentation, frequency and amounts are often inappropriate. This implies that the dairy animals may not be getting adequate feed. Reports by Gibbons et al. (2010) and Munthali et al. (1992) allude to inadequate feeding of dairy animals by smallholder farmers. Munthali et al. (1992) reported that the quality of the feed available was insufficient to meet the nutritional requirements of dairy cows. Even where feeds were available, another challenge cited is the knowledge of extension workers in formulation of suitable rations.

The feeding of mostly maize bran and grasses may also mean that important nutrients such as protein and some minerals may be inadequate in the diets. Crude protein (CP) content in maize bran is 11% (Mtimuni 1995), while in grasses, it is mostly below 7% during the dry season (Mtimuni 2011). Moran (2009) reported that CP requirements range from 10% to 18% depending on stage of lactation. This shows that maize bran barely meets the requirement for dry cows while grasses are very deficient in CP. The inadequate feeding coupled with some nutrient deficiencies results in negative energy balance, which in turn contributes to low fertility. Friggens (2003) reported that animals with constrained energy reserves either reduce their 'reproductive burden' or delay onset of the next reproductive cycle. For a dairy cow carrying one foetus at a time, reduction of the 'reproductive burden' implies no pregnancy and delayed onset of reproductive cycles means long calving intervals. Lanyasunya et al. (2005) reported that poor nutrition is the major cause of infertility and low productivity of dairy cattle under smallholder systems and recommends more attention to be given to nutrition for productivity to improve.

The findings on the feeding system have implications on cow productivity including fertility. Zero grazing has advantages in that animals are protected from between herd disease transmission for diseases such as East Cost Fever. In addition, it is relatively easier for farmers to observe animals on heat and call for timely service. However, the system has a disadvantage where AI services are inefficient, and this has been the case in Malawi for some time (Chagunda et al. 1998). There are high chances of animals not being served even when oestrus is correctly detected. At the same time, the cows miss out on the chances of timely insemination that could occur with natural mating if they grazed with other herds running with bulls.

Housing system

The cattle housing structures vary in terms of construction materials used. Roofs are made of thatch grass, iron sheets or a combination of plastic sheets and thatch grass while the floors are from mud, concrete or sand with or without beddings. The baseline survey results showed that irrespective of construction material, most houses (83%) were adequately roofed with a few that were not roofed (11%) or inadequately roofed (6%). A few (23%) farmers used beddings on the floors with Mzimba District having about 51% of these. About 54% of the pens had good drainage. Feed stores, milking parlours, feeding and water troughs were present in 57%, 79%, 77% and 80% of the farms, respectively.

The results suggest that some farmers have not fully embraced the importance of proper housing of dairy animals. Inadequate roofing and poor drainage can result in accumulation of slurry during the rainy season, which would be difficult to clean given the many tasks farmers need to perform particularly in the rainy season when crop production is of prime importance. Hence, accumulation of slurry is inevitable and is observed in most dairy farms. Accumulation of slurry would be detrimental to the animals and provide a medium for pathogens as well as high chances of milk contamination. The use of iron sheet roofs also needs to be critically evaluated because they conduct heat and could be associated with heat stress mainly in the hot-dry and hot-wet seasons.

Dairy breeds and population

The Malawi Government has recommended Holstein–Friesian, Ayrshire and the Jersey as dairy breeds (DAHLD 2006). Results from the baseline survey showed that most farmers (54%) owned the Holstein–Friesians with no significant differences ($p>0.05$) between districts. Table 1 shows that the number of Holstein–Friesians was significantly higher ($p<0.05$) than that of other breeds while the numbers of the rest of the breeds were not significantly different ($p>0.05$) from each other. Other farmers kept Holstein–Friesian crosses with the Malawi Zebu (16%) and Jerseys (13%). Respondents in Thyolo District kept the highest percentage (80%) of pure Holstein–Friesians and their crosses with Malawi Zebu. The rest of the districts were also dominated by farmers owning Holstein–Friesians but with noticeable percentages of farmers owning Jerseys and Jersey × Malawi Zebu crosses. Lilongwe District had the highest percentage (32%) of farmers keeping Jerseys, followed by Mzimba (25%). The differences in breeds kept could be attributed to availability of the animals as provided by NGOs and other supporting agents.

The national dairy population database does not specify the dairy breeds. Instead, the cows are only classified as either pure or crossbreds. The data show that there are more crossbreds than purebreds with crossbreds accounting for 79% of the dairy population in 2010. The trend is the same throughout all the ADD as shown in Table 2. The table shows that the crossbreds account for more than 55% of the dairy herd in each ADD with Salima ADD having a dairy population comprised of crosses only. The ADDs in the northern milk-shed area (Karonga and Mzuzu) have relatively higher proportions of purebreds compared to the central and southern milk-shed areas. The differences in the distribution of the breeds could be due to differences in availability and pricing of the cattle. Crossbreds are relatively more available than purebreds. Their availability is mostly through AI births and sales from Government farms. As such, they are relatively cheaper than the purebreds.

The presence of more purebreds in the north could reflect that there are more farmers that can afford the purebreds or there are more NGOs supporting purebreds supply to farmers in the northern milk-shed area than the other milk-shed areas. The national census data indicate that there is a high proportion of crossbreds compared to the trend in the survey findings where farmers reported more purebreds. The reason for this discrepancy could be farmers not being able to distinguish between purebreds and high-grade crosses. It may also be a reflection of lack of proper record keeping by the farmers as well as lack of a proper national inventory.

Table 2 also shows that the highest proportion (73%) of the dairy population is in Blantyre ADD, while the populations in Mzuzu (11%) and Lilongwe (8%) come second and third, respectively. This shows that dairy production is concentrated around the cities with most production in the southern region. Imani Development Consultants (2004) reported that dairy production is most developed in the southern region and attributed this to small land holding size, which favours dairy production. Blantyre ADD is also within the Shire Highlands, which is characterized as having favourable climate with relatively low disease challenges (Imani Development Consultants 2004). Shire Valley ADD has the lowest (0.2%) proportion of dairy animals followed by Karonga (0.5%) and Salima (0.6%) ADDs, respectively. The reason for this could be that the respective agro-ecological zones (AEZ) do not favour dairy production and that dairy production support in these ADDs is relatively lower than in the other ADDs. Shire Valley ADD is within an AEZ characterized by low altitude and low annual rainfall (<600 mm) while Karonga and Salima ADDs are in the lakeshore low altitude rain shadow area with 600–800 mm annual rainfall (Jere 2007).

Overall, the dairy population increased by 65% from 2004 to 2010. Figure 2 shows the trend in the population of

Table 1 Breeds of dairy cattle owned by smallholder farmers in Mzimba, Kasungu, Lilongwe and Thyolo Districts

	Breed				
	Holstein–Friesian	Jersey	Holstein × local cross	Jersey × local cross	Malawi Zebu
n	97	24	29	19	12
Number of animals (mean ± SD)	55 ± 36.6^{a}	12 ± 8.6^{b}	16 ± 5.1^{b}	6 ± 5.3^{b}	6 ± 5.3^{b}

Means with different superscripts in the same row are significantly different ($p<0.05$, Student-Newman-Keuls test)

dairy cattle from 2005/2006 growing season. The figure shows that the total dairy population has been increasing over the years. The rate of increase of pure breeds decreased sharply from 61% to 20% between 2006/2007 and 2007/2008 growing seasons and gradually increased to 30% in 2009/2010. The increase rate of crosses has been declining throughout the years. The rate declined from 24% in 2005/2006 to 10% in 2009/2010 growing season. The results may be a reflection of the importation and reproductive management of dairy cattle in the country. The high rate of purebreds increase in 2005/2006 could be due to a high number of animals that was imported with slightly fewer animals imported in 2009 and 2010. The perpetual decline on the increase rate of crosses could be an indicator of low replacement rate of the dairy herd, which could be related to cow fertility. Low replacement rate is also evidenced in the dairy herd structure obtained from both the survey and data from the ADDs as discussed below.

Herd structure

In the smallholder dairy farms, the average herd size is generally two to four cows (Kasulo et al. 2010; Chagunda et al. 2006; Chintsanya et al. 2004). Chagunda et al. (2006) and Kasulo et al. (2010) reported average herd sizes of 3.5 and 2.2 for Lilongwe and Mzuzu milk-shed areas, respectively. Results from the survey showed an average herd size of 2.2 ± 1.6 (SD) with no significant difference between districts (Table 3). The herds are mostly comprised of cows. A very small percentage of farmers (9%) own bulls. The average number of cows per farm was 1.2 ± 0.78. The range of the number of cows was 0–4 while Chintsanya et al. (2004) reported a range of 2–4 cows for dairy farmers in Malawi. The differences in the minimum could be attributed to Chintsanya et al. (2004) reporting on well-established dairy farmers while the survey included even new entrants into dairy farming.

The herd structure shows that cows make up 36% of the herd while heifers and heifer calves make 19% and 15%, respectively. Based on data from ADD annual reports, a similar herd structure is observed for Lilongwe, Mzuzu and Blantyre ADD herds (Fig. 3). The percentage of the different classes of the herds remained relatively stable and similar between the ADDs since 2007. The average proportion of cows, heifers and heifer calves between 2007 and 2010 within the ADD herds was 45%, 21% and 12%, respectively.

Heifers and heifer calves are necessary as replacements for cows in the dairy herd, and surplus heifers are an important component of the income from dairy production. Therefore, proper reproductive management is important for successful dairying (Stewart 2005). Table 3 shows that the percentage of heifers is slightly below what may be considered sufficient as replacement stock while Fig. 3 shows that the ADDs could be within the ideal proportion if it is assumed that cows remain in a herd until five lactations (Gietema 2005). Due to few numbers of cows kept, it is more likely that farmers in Malawi may keep cows for more than five lactations as similar farms in Tanzania reported to eight lactations (Bee et al. 2006). For cows remaining in the herd for four to five lactations, 20% to 25% should be replaced every year. However, if it is taken into account that farmers own 1.2 cows on average, then the current proportions of heifers may not enable stable herds to be kept. This is evident when calculations are made according to Bebe (2008a).

Table 2 Distribution of dairy cattle population by Agricultural Development Division in Malawi in 2007/2008

Population	KA	MZ	KU	LL	SA	MH	BT	SV	Total
n	147	3,328	1,101	2,516	194	945	21,806	55	30,092
Pure breeds (%)	45	43	35	32	0	10	11	4	17
Crossbreeds (%)	55	58	65	68	100	90	89	96	83

KA Kasungu, *MZ* Mzuzu, *KU* Kasungu, *LL* Lilongwe, *SA* Salima, *MH* Machinga, *BT* Blantyre, *SV* Shire Valley

Data analyzed from DAHLD (2008)

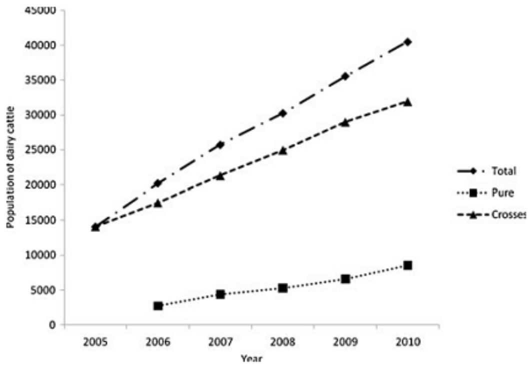

Fig. 2 Dairy cattle population trend in Malawi from 2005 to 2010 (Data Source: DAHLD 2010)

Bebe (2008a) reported that heifers for stock replacement are described as the number of heifers surviving to breeding age and are expressed as the number of heifers per cow leaving the herd through death or sales. To maintain herd size, the number of heifers per cow leaving the herd has to be equal to or more than one. Table 3 shows that the average number of cows and heifers per farmer is 1.16 and 0.85, respectively. Assuming that one cow in the herd dies, then the replacement heifers per cow is 0.73 suggesting that the current herd structure cannot be maintained. Cow mortality is assumed based on mortality rates reported in the baseline survey (14%) and other similar production systems (19% and 12%) in Zimbabwe (Masama et al. 2006) and Kenya (Bebe et al. 2003), respectively.

It would be reasonable for farmers to target having at least 25% heifers for their herds to be maintained. Moran (2009) illustrated that a system with 36% heifers, for example, would have sufficient replacement stock as well as enable sale of breeding stock or allow higher culling rate to improve herd genetics. Most smallholder farmers may not necessarily aim for expanding herds but would benefit from sales of breeding stock.

Bebe (2008a) reported similar results for smallholder dairy farmers in semi-zero and zero grazing systems of Kenya. The reason for low replacement stock could be a reflection of low fertility, poor reproductive management and/or deliberate decisions by farmers. Bebe (2008b) reported that some Kenyan farmers deliberately have few replacement animals to minimize labour for feeding animals. Bebe (2008b) showed that the proportions of heifers to cows among smallholder farmers in Kenya were related to feeding resources. Farmers that practiced zero grazing kept the proportions low through early weaning and sales, and it was concluded that availability of sufficient pastures determined the ability to rear adequate stock replacement heifers. In Malawi, it is not apparent that farmers deliberately keep the replacement stock low. The low numbers of replacement stock could be more as a result of poor reproductive management and hence low fertility. Herds that cannot be maintained internally often rely on external replacement and this is the situation in Malawi. The implication is that the farmers can hardly produce surplus stock to be sold to other farmers. Hence, if dairy production is to expand, importation of dairy stock has to be in place.

Breeding

Cows and heifers are mated using AI (55%) or bulls that are hired (36%) or borrowed (1%) from other farmers. Most of the semen used is from the National AI Centre (NAIC) based in Blantyre ADD. NAIC currently has four Holstein bulls from which semen is collected, processed and distributed throughout the country (Mayuni 2003). However, the performance of the bulls has not been evaluated (Gondwe 2011). The farmers target to inseminate the animals immediately after the recommended 60 days voluntary period. However, semen availability is often a challenge due to storage and transportation problems (Masangano et al. 2009).

There were significant differences between districts (χ^2; $p<0.05$) between use of AI and bulls. AI was mostly used in Thyolo (74%) and least in Kasungu District (36%). Hired bulls were mostly used in Kasungu District (64%) and least in Thyolo (19%). The reason for these differences could be associated with proximity to the source of semen straws. Thyolo District is closest to NAIC; hence, farmers from

Table 3 The structure of dairy herds among smallholder farmers in Mzimba, Kasungu, Lilongwe and Thyolo Districts

Descriptive statistics	Number of animals owned							
	Cows	Heifers	Pregnant Heifers	Pregnant cows	Bulls	Male calves	Female calves	Total
n	148	81	56	63	62	93	87	180
Mean	1.2	0.6	0.2	0.4	0.4	0.9	0.7	2.2
SD	0.8	0.7	0.5	0.7	0.9	0.7	0.7	1.6

Source: Baseline survey

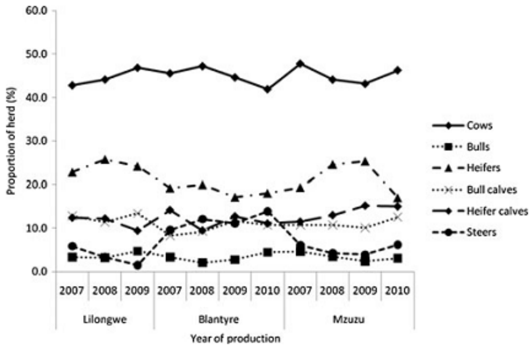

Fig. 3 The dairy herd structure in Lilongwe, Blantyre and Mzuzu ADDs between 2007 and 2010 (Data source: BLADD 2010; LADD 2010; MZADD 2010)

Thyolo could access semen straws relatively easier than those in the Central and Northern Regions. Mayuni (2003) reported low conception rates as distance from NAIC increased. It is possible that farmers in the north milk-shed area rely less on AI after experiencing low conception rates with use of semen from NAIC.

Another reason for more AI users in Thyolo could be the availability of well-trained and experienced AI technicians as dairy farming is more organized and intensive in BLADD (CYE Consult 2009). In other areas such as Kasungu and Mzimba, AI technicians have challenges such as lack of transport, shortage of AI equipment and high AI technician farmer ratios (Masangano et al. 2009). These challenges lead to delayed or missed inseminations thereby making AI seem unreliable to farmers.

Herd health

Farmers mostly access health services through Government assistant veterinary officers, private veterinary services and drug revolving funds. Munthali et al. (1992) reported that the health services were not adequate, while Mwale et al. (1999) reported that animal health problems were ranked first among problems that dairy farmers encountered. Survey results showed that 11% of the farmers did not treat sick animals due to either unavailable or unaffordable drugs.

Farmers report various health challenges in dairy production. A study by Chindime (2008) showed percentages of farms that reported particular diseases as follows: mastitis (32%), East Coast Fever (ECF, 28%), fever (16%), coughing (8%), pink eye (7%), diarrhoea (6%) and sore feet (5%). These challenges are similar to those found in the baseline survey where mastitis, ECF and diarrhoea were reported by 35%, 19% and 16% of the farms, respectively. Other diseases reported in the survey were black quarter, tuberculosis, brucellosis and foot and mouth disease. Munthali et al. (1992) reported that health services were biased towards control of ECF with important health problems such as gastro-intestinal parasites and pneumonia not receiving adequate attention. This is in agreement with Huttner et al. (2001) who reported high incidences of *helminthiasis*, *fascioliasis* besides tick borne diseases. In addition, *Trypanosomiasis* is reported in cattle close to national parks and game reserves while black quarter is prevalent in some areas where it is considered endemic. Some zoonotic diseases such as tuberculosis and rabies are also reported.

The results show that dairy cow health is a challenge among smallholder farmers. Disease control is further limited by not treating sick animals or waiting too long before diseases are reported. Absence of detailed record keeping and disease surveillance makes it difficult to quantify the actual prevalence and severity of diseases affecting dairy animals. Huttner (2000) reported malnutrition and poor animal husbandry as the major predisposing factors to poor animal health among smallholder farms. The combination of health and nutrition challenge in dairy production implies further suppression of animal productivity in terms of milk yield and fertility. It is therefore important to have in place programmes that constantly and systematically monitor and support disease control while providing timely treatments and vaccinations as need arises. This requires the collaboration and participation of farmers, service providers and other relevant stakeholders.

Herd productivity

Milk yield varies depending on the level of management and genotype used. Malawi Zebu produces 2–4 kg/day (Mwale et al. 1999) while crossbreds produce daily averages ranging from 3 to 11 kg (Chindime 2008; Mwale et al. 1999; Agyemang and Nkhonjera 1990; Mussa et al. 1986). The yields are generally low when the potential milk yield of the breeds used is considered. A wide variation in milk yield is observed between farms within individual studies, which might be a reflection of differences in feeding levels and health of the animals. Farmers with access to resources are associated with high yields (Chindime 2008). The wide variation between farms indicates that the potential to improve yield by adjusting management in terms of feeding and health exists. Another challenge related to cow productivity is the apparent lack of understanding among farmers of the link between management input and productivity. Most farmers record milk yield in order to track their payments from milk sales (Chindime 2008). However, the farmers seem not to evaluate milk yields to reflect on inputs used or level of management. It would be worthwhile to help farmers appreciate this linkage.

In addition to milk yield, body condition score (BCS) is an important trait which forms an integral part of dairy records in many countries and informs cow productivity. BCS is generally recognized to provide a measure of the body energy reserves (Roche et al. 2009). Low BCS during late gestation and early lactation is associated with delayed resumption of ovarian cyclicity which could reduce chances of subsequent reproductive success (Chagas et al. 2007) in terms of parturition and rebreeding interval. Where resources are limited, there may be an advantage in a greater interval between pregnancies, but the target is to improve resource availability to increase dairy productivity. Currently, smallholder farmers in Malawi do not monitor BCS. There is a need to demonstrate the relationship between BCS, milk yield and management input and link this to profitability and fertility so that farmers understand their relevance and hopefully adopt record keeping, evaluation and recommended husbandry techniques.

Status of cow fertility

Calving rates

Calving rate is one of the simplest means to estimate fertility. It is a retrospective measure, which is useful for evaluating overall herd performance in a given period. Ramsey et al. (2009) reported that calving rate gives an indication of production management skills and is negatively related to production costs. The overall calving rates in the ADDs ranged from 22% to 61% with the trend fluctuating between breeds and over time (Table 4) but with no significant differences ($p>0.05$). Calving rates based on artificial insemination records for the ADDs are even lower with Mzuzu ADD having the lowest rate of 16% in 2008. Lilongwe and Blantyre ADDs had relatively higher calving rates than Mzuzu ADD. However, the number of inseminations reported for Lilongwe ADD is much smaller than the population of dairy animals in the ADD. This may mean that recording of AI in Lilongwe ADD may not be up to date or that more farmers rely on natural service than AI.

The differences in calving rates between ADDs could be attributed to differences in recording skills and frequency as well as availability of AI services. MZADD is furthest from the major source of semen. Mayuni (2003) reported low conception rates as distance from the source of semen increased. The low conception rates were associated with poor semen quality. Reports from respective ADDs indicate lack of AI equipment and inadequate AI technicians as the major challenge to AI service delivery (LADD 2010; BLADD 2009; MZADD 2009). In addition, Mzuzu ADD cites irregular supply of semen and liquid nitrogen (MZADD 2009) while Lilongwe ADD also cites lack of incentives for farmer AI technicians as a challenge (LADD 2010).

There could also be other factors such as experience and transport availability for AI technicians and the ability of farmers to detect and report heat on time as well as poor health, inadequate nutrition and farm management skills. For instance, in 2009, BLADD reported an overall pregnancy rate of 71%, but calving rate came down to 47%. This may be reflection of challenges in animal health and farm management, which result in mortality, abortions and still births. The low calving rates could also be related to inadequate nutrition as discussed above. Calving rate is influenced by factors related to animals, the farm management as well as insemination services (Nordin et al. 2007), and these may be difficult to isolate unless detailed studies are carried out.

Generally, the AI records from the ADDs are not clear on whether the births reported are only from AI or include births from natural service. As it is established that a

Table 4 Calving rates of dairy cattle in Blantyre, Lilongwe and Mzuzu ADDs in 2007, 2008 and 2009

Variable	Year	Breed	Percentage in each agricultural development division		
			Blantyre	Lilongwe	Mzuzu
Calving rate	2007	Crosses	35 (11,195)[a]	32 (1028)	36 (1,058)
		Pure	29 (1,450)	53 (436)	29 (693)
	2008	Crosses	28 (13,289)	36 (1148)	40 (1,265)
		Pure	22 (1,861)	29 (609)	28 (1,022)
	2009	Crosses	40 (14,215)	34 (1,392)	44 (1,322)
		Pure	36 (1,994)	30 (869)	29 (1,118)
	2010	Crosses	35 (16,263)	–	61 (1,395)
		Pure	49 (2,328)	–	22 (1,119)
AI Calving rate[b]	2007		28 (4,401)	33 (75)	26 (377)
	2008		31 (5,013)	55 (92)	16 (200)
	2009		55 (8,081)	62 (8)	–

Data analyzed from BLADD (2010); LADD (2010); MZADD (2010)

[a] Figures in parenthesis indicate number of cows

[b] Calculated from cows served through artificial insemination only

considerable proportion of farms depend on natural service, it would be worthwhile to present records on natural service and subsequent births separately. Despite the shortfalls, the data provide an indication of the existing calving rates, which are generally low but improving in LADD and BLADD. According to Perera (1999), acceptable calving rates for smallholder farms should be more than 70%. The calving rates in the ADDs are below 70% and similar to those reported for Zimbabwean smallholder dairy farms where calving rates were 30% (Masama et al. 2003) and 53.2% (Masama et al. 2006). This may be depicting poor reproductive management coupled with inadequate nutrition as discussed above. This implies that the farmers need further capacity building in dairy cattle management besides the requirement for improved AI and extension service delivery.

Calving interval

Calving interval (CI) is a trait that shows overall fertility over time, and Mukasa-Mugerwa (1989) reported that it is the best measure of reproductive efficiency. As with calving rate, it is a retrospective measure that is used to evaluate farm reproductive efficiency. BLADD reported overall CI of 457±59 days (with a range of 405 to 540 days) in 2009, while this information was not available from the other ADDs. The CI is lower than average of 485 days reported by Agyemang and Nkhonjera (1990) for smallholder dairy herds in Southern Malawi. The difference could be attributed to the current herds being a mixture of purebreds and crossbreds while (Agyemang and Nkhonjera 1990) reported CI for crossbreds only. The CI is also shorter than the average CI reported in smallholder farming systems in Tanzania (Swai et al. 2005), Ethiopia (Lobago et al. 2007; Shiferaw et al. 2003) and Zimbabwe (Masama et al. 2003) which were all greater than 500 days. Perera (1999) suggested CI between 13 and 14 months (390–420 days) as acceptable under improved smallholder conditions. Other studies among smallholder farms in Tanzania and Ethiopia have shown CI less than 420 days (Chenyambuga and Mseleko 2009; Yifat et al. 2009) indicating that achieving lower CI is possible. This suggests that there is room for improvement on the current CI in Malawi.

Calving to conception interval

Calving to conception interval is an integral part of the calving interval and is directly affected by the voluntary waiting period before service. Generally, the voluntary waiting period is 60 days (Perera 1999). Among farmers that rely on AI services, this period may be prolonged by availability of AI services, inaccurate heat detection, absence of observable heat and/or prolonged post-partum anoestrus. The survey provided an indication of days to service based on verbal reports by farmers interviewed. The days ranged from 60 to 270 with an average of 107±38 days and a median of 90 days. However, only a small proportion of farmers (4%) from Thyolo and Kasungu indicated that they served their animals more than 150 days from calving. If this proportion of farmers is excluded from the data, the average is 97±24 days (Table 5).

There were significant differences between districts ($p < 0.05$) with 79% and 73% of farmers in Mzimba and Lilongwe Districts serving their animals within 90 days after calving compared to 49% and 29% of the farmers from Thyolo and Kasungu Districts, respectively. This might be an indication of differences in access to animal breeding information or technology adoption rates between districts. Generally, the days from calving to service are higher than the ideal of 60 to 65 days. Suggested acceptable days to service for smallholder dairy farms in the tropics are less than 90 days (Perera 1999), while Moran (2005) reported acceptable calving to conception interval of less than 115 days. Some farmers in Malawi could be within these suggested intervals, while others could be above the intervals. There is need for further improvement on breeding practices in order to shorten the CCI and subsequently the CI.

For some farmers, a CCI of less than 115 days is not possible due to inefficient AI service delivery. In other smallholder farms in the tropics, CCI above 115 days are also reported. Yifat et al. (2009) reported CCI of 135 days

Table 5 Number of days from calving to service for dairy cattle in Mzimba, Lilongwe, Kasungu and Thyolo Districts

District	Number of days from calving to service					
	n	Mean	SD	Median	Minimum	Maximum
Mzimba	51	91[a]	23	90	60	150
Lilongwe	26	94[a]	13	90	60	120
Kasungu	11	117[b]	25	120	90	150
Thyolo	36	103[a]	28	90	60	150
Total	124	97	24	90	60	150

[a]Means with a different superscript within the same column are significantly different ($p < 0.05$, Student-Newman-Keuls Test)

in Ethiopia. The long CCI could also be exacerbated by prolonged post-partum anoestrus as a result of inadequate feeding and stress as discussed above. The management-related issues such as accurate heat detection, nutrition and health status may also largely contribute to the current status of CCI and CI.

Pregnancy diagnosis

A few farmers (23%) indicated that pregnancy diagnosis (PD) was done through rectal palpation by either the government (65%) or farmer AI technicians (35%) following an insemination. The average timing of the PD was 91± 33 days. Other farmers indicated that they diagnosed pregnancy on their own using non-return to oestrus and physical appearance as indicators. The PD by the technicians is done too late for timely repeat inseminations. The rectal palpation method that is used can be used as early as 30 to 40 days from insemination (Fricke 2010; Sheldon and Noakes 2002). It is worthwhile to encourage farmers to conduct PD using the simplest method, non-return to oestrus. Although the non-return to oestrus is not reliable (Fricke 2010) due to missed oestrous behaviours, it would be much better in this case (with appropriate heat detection skills) than waiting for a technician to come for rectal palpation after 3 months.

Conclusion

Management and fertility of dairy cows among smallholder farms is faced with both challenges and opportunities to improved productivity that are related to feeding, housing, health and breeding systems. Both the challenges and opportunities are influenced by the extent to which farmers have access to important services such as extension, health, breeding and finance. Feeding systems used seem inadequate in terms of quantity and quality. However, opportunities for improvement are available in terms of availability of technologies and stakeholders to promote the technologies and build capacity in farmers and extension workers. Dairy housing also needs to improve with some aspects, such as the most suitable construction materials, needing further assessment. The efficiency of the health and breeding systems also needs improvement. There is need for systematic health surveillance and recording to be in place in order to monitor health and reproductive management in the farms. These would help to identify specific gaps and suitable approaches to be used to address the issues

The potential for improved productivity is evidenced by wide variation in the magnitude of various traits that were analyzed. Improvement in service delivery and further capacity building of both farmers and extension staff is required in order to improve dairy management skill and subsequent productivity. Further detailed research in specific aspects of feeding, housing, health and breeding systems would help to identify specific interventions that could be used to improve dairy cow productivity.

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